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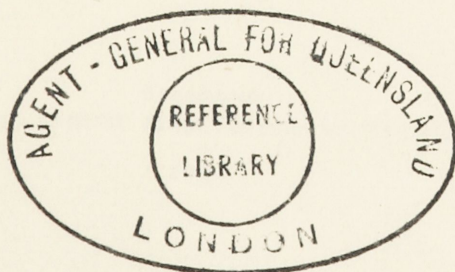
## QUEENSLAND.

### INDUSTRIAL MINERALS.

A review of Occurrences, Treatment, Uses, Values, and Production, with special reference to Queensland's Resources, by B. Dunstan, Chief Government Geologist.

Article 1.	SALT
" 2.	ASBESTOS
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" 4.	MOLYBDENITE
" 5.	PLATINUM
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" 7.	GRAPHITE
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" 9.	ARSENIC

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**SALT.**

**REPRINT.**

**Article 1 in INDUSTRIAL MINERALS**

*By B. DUNSTAN, Chief Government Geologist.*

(Publication No. 263, in Part)

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*Queensland Geological Survey, Department of Mines, Brisbane.*

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A review of Occurrences, Treatment, Uses, Values, and Production,  
with special reference to Queensland's Resources.



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# Article 1.—SALT.

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## Article 1.—SALT.

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### Occurrences in Queensland.

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The occurrences of large deposits of salt in Queensland are not very numerous, and nearly all are situated in areas so remote that little encouragement can be given to their exploitation. Localities where salt can be manufactured from sea water or from spring water, however, are common, and a few places are distinctly favourable for the manufacture of the commodity on a large scale.

Salt is produced by the natural evaporation of sea water on many parts of the coast, and the salt pans of Gladstone and of Port Alma, at the mouth of the Fitzroy River, are well known. Within Moreton Bay, near Brisbane, and at Sandgate, salt has been manufactured from sea water, and numerous places on the east coast are apparently suitable as sites for salt making by solar evaporation. On the southern shores of the Gulf of Carpentaria clay pans exist which annually accumulate vast quantities of salt, more particularly in the areas between Burketown and the boundary of the Northern Territory, and a very favourable opinion has been formed about the natural advantages of this part of the State for the manufacture of salt.

In the Western districts a large number of artesian bores are spread over an immense area of country and show that at varying depths brine beds exist, mostly above beds containing fresh water. Then there are the salt lakes to the south of Thargomindah; the salt lake in the Muncoonie Group of lakes near the south-western corner in latitude  $25^{\circ} 10'$ ; lakes and lagoons around Lake Philippi (itself fresh water) close to the western border in latitude  $24^{\circ} 15'$ ; Lake Kallidewarry, about 45 miles to the S.S.W. of Lake Philippi—perhaps the largest deposit in the State; Lake Galilee, 50 miles north-east of Aramac; Lake Buchanan, 70 miles to the S.S.E. of Pentland, a railway station between Hughenden and Charters Towers; Lake Emma, to the north of Welcome, a railway station 40 miles westerly from

Cooktown; and lastly the brine beds which have been discovered in boring for fresh water on Casuarina Island near the mouth of the Fitzroy River.

### Other Localities where Salt is Found.

In *New South Wales* there are salt lakes and springs in the western districts and salt water in the artesian bores, while in *Victoria* there are a large number of salt lakes in the Western District and in the Mallee country.

In *Western Australia* salt deposits are formed by the evaporation of the waters of inland lakes, the most important being the Yarra Yarra lakes, 100 miles north of Perth and close to Carnamah Railway Station, and the Hutt Lagoon at Lynton near Port Gregory, 45 miles N.N.W. of Geraldton. Rottenest Island near Fremantle and Middle Island near Esperance are other localities.

In *South Australia* large deposits of salt occur at Lake Fowler and other localities on Yorke Peninsula, and also at Lake Bumbungie, 20 miles to the north of the Gulf of St. Vincent. An immense quantity of salt exists in an area of 60 square miles at Lake Hart, 120 miles to the north-west of Port Augusta at the head of Spencer's Gulf, and a large amount has also accumulated on Kangaroo Island, while to the north of the State numerous other deposits are said to occur. At Port Price, Yorke Peninsula, salt is being manufactured from sea water.

In the *Northern Territory* salt deposits exist along the coastal areas of the Gulf of Carpentaria, particularly about the lagoons near the mouths of the McArthur River and Whearin Creek and on the Sir Arthur Pellew Islands. Regarding Whearin Creek, a large deposit has been discovered in what is called the Salt Arm, about 6 miles up from the mouth on the eastern side. Very saline waters occur in some of the bore waters of Brunette Downs on the Barkly Tableland, but salt lakes in the district are unknown.

Amongst *Other Countries* the United Kingdom and the United States are the largest salt producers, other countries producing the article being, in their order of importance, Germany, Russia, Austria, Hungary, France, India, Spain, Greece, Canada, Algeria, Peru, and South Africa. China must be a large producer, but no authentic records have been kept of the production of that country.

### Geological Notes.

Salt occurs in nature either as beds of salt interstratified with sedimentary rocks or as superficial accumulations on flat

clayey lands. Rock salt deposits occurring at depths were formed on the surface and became overwhelmed by clays and sands, and while some are comparatively recent in formation, others are of great age. Some of the well-known deposits in the world are over 1,000 feet thick and beds of salt without any admixture of impurities or any interbedding of sediment are known which are several hundred feet thick. The mineral also forms as an impregnation of rocks, more particularly clays and sandstones, and is commonly an incrustation on soils or on the roofs and walls of caves, while in solution it impregnates beds associated with oil seepages, and is a constituent of the waters of many lakes, artesian basins and springs.

Sea water usually contains from  $2\frac{1}{2}$  to 3 per cent. of salt, and, with rock salt deposits, is the great source of the supply of the article. Some isolated seas and inland lakes, such as the Red Sea and the Caspian, have a much larger percentage of salt in solution than is contained in sea water, and the Great Salt Lake in Utah has more than four times the percentage.

Table 1 contains the selected analyses of a number of waters, from which a comparison can be made of the salt contents of various oceans, seas, and lakes.

TABLE 1.—ANALYSES OF SEA AND LAKE WATERS.

			Mediterranean Sea.	Pacific Ocean.	Atlantic Ocean.	Red Sea.	Great Salt Lake.	Dead Sea.	Lake Coranga- mite, Victoria	Lake Buchanan Queensland.
Sodium Chloride	..	..	2.719	2.587	2.755	3.023	13.126	6.578	4.093	2.911
Magnesium Chloride	..	..	0.613	0.434	0.326	0.404	1.171	10.548	0.324	.007
Potassium Chloride	..	..	0.001	..	..	0.288	..	1.398	..	.004
Calcium Chloride	..	..	..	..	..	..	..	2.894	..	..
Magnesium Sulphate	..	..	0.701	0.061	0.110	0.274	..	..	..	..
Potassium Sulphate	..	..	..	0.135	0.171	0.295	0.532	..	0.094	..
Calcium Sulphate	..	..	0.015	0.204	0.162	0.179	0.169	0.088	0.080	.041
Magnesium Carbonate	..	..	0.019	..	..	..	..	..	..	..
Silica, Alumina, &c.	..	..	..	..	..	..	..	..	..	.037
Sodium Bromide	..	..	0.055	0.040	0.032	0.064	..	0.251	..	..
Magnesium Bromide	..	..	..	..	..	..	..	..	0.015	..
Total solids	..	..	4.123	3.461	3.556	4.537	14.998	21.757	4.606	3.000
Sp. gravity	..	..	1.025	1.023	1.024	1.030	1.107	1.160	1.031	1.020

There are many occurrences of rock salt in America, Europe,

Asia, and Africa, but up to the present no deposits have been recorded in Australia except those formed as superficial deposits in dry lakes.

It remains to be proved, however, amongst the great number of brine beds met with in the Australian artesian basin, whether beds of rock salt do not occur associated with them. Gypsum, the common associate of rock salt, is frequently found in small quantities in artesian bores, and the manner of conducting boring operations is such that beds of rock salt could be passed through in artesian strata without being noticed. The conditions generally prevailing in rock salt areas in other countries are so much like those of the artesian basin of Queensland and New South Wales that it is difficult to realise that deposits have not been passed through in boring for water, more particularly as the whole of the beds in which the artesian water occurs—below marine strata—must have been an immense lowlying area where inland lake conditions once existed.

In Table 2 are given six analyses of rock salt from different countries to show the purity of the salt as it is taken from the mines.

TABLE 2.—ANALYSES OF ROCK SALT.

—	Saltville, U.S.	Pearl Co., N.Y. (U.S.A.)	Cheshire, England.	Dièuze, France.	Algeria.	Hall, Tyrol.
	%	%	%	%	%	%
Sodium Chloride .. ..	99.08	96.88	93.20	97.70	99.30	99.43
Magnesium Chloride .. ..	..	0.10	0.03	..	..	0.12
Calcium Chloride .. ..	trace	0.16	0.12	..	..	0.25
Sodium Sulphate .. ..	..	..	0.65	..	..	..
Calcium Sulphate .. ..	0.44	0.44	0.95	2.05	0.50	0.20
Magnesium Sulphate .. ..	..	..	0.10	0.15	..	..
Alumina, Silica, &c. .. ..	0.47	1.21	1.00	..	0.20	..
Moisture .. ..	..	1.21	4.05	0.10	..	..
Total .. ..	99.99	100.00	100.00	100.00	100.00	100.00

All the salt lakes of Queensland are in depressed areas with no outlets for the waters which flow into them, and so shallow

that they usually become quite dry in winter time. Mostly they are in districts far from centres of population and only occasionally do those residing near the deposits make use of the salt they contain. Nothing has been ascertained regarding the depth or extent of the deposits, and in only a few instances have analyses of the salt been made.

In Table 3 are given the analyses of crude lake salts from localities in Queensland, Victoria, South Australia, and Western Australia.

TABLE 3.—ANALYSES OF CRUDE SEA AND LAKE SALT.

	Lake Fowler, S.A. (Castle Co.)	Lake Hart, S.A.	Princess Charlotte Bay, Q.	Lake Buchanan, Q.	Hare Creek, Escott Burketown, Q.	Typical Productive Lakes on Yorke Peninsula.		Whearin Cr., Gulf of Carpentaria, N.T.	Lake St. Mary, West. District, Vic.	Hutt Lagoon, Lyndon, W.A.
						1	2			
Sodium Chloride	96.86	95.93	92.17	97.02	95.32	94.70	95.96	99.45	91.63	99.55
Magnesium Chloride	1.01	0.17	1.22	0.22	0.11	0.71	0.47	0.14	2.40	0.15
Potassium Chloride	..	0.39	0.23	0.15	..	0.24	0.19	0.11	0.21	..
Calcium Chloride	..	..	..	..	..	..	..	..	..	..
Sodium Sulphate	..	..	4.14	..	0.54	..	..	..	..	..
Magnesium Sulphate	..	0.02	..	..	..	0.25	0.55	0.21	4.86	0.08
Calcium Sulphate	0.85	2.09	1.31	1.38	0.90	1.32	0.75	..	0.81	..
Potassium Sulphate	..	..	..	..	..	..	..	..	..	0.18
Magnesium Carbonate	..	..	..	..	..	..	..	..	..	..
Calcium Carbonate	..	..	..	..	..	..	..	..	..	..
Magnesium Bromide	..	..	..	..	..	..	..	..	..	..
Sodium Bromide	..	..	trace	..	..	..	..	..	..	..
Silica, Iron, Alumina, &c	1.25	0.18	0.53	1.23	0.80	0.20	0.48	0.03	..	0.04
Water .. ..	..	0.56	..	..	2.30	2.38	1.47	..	..	..
Totals ..	99.97	99.34	99.61	100.00	99.97	99.80	99.87	99.94	99.91*	100.00

\* The brine yields 17.66 per cent. of total solids.

The brine beds of Casuarina Island, which no doubt continue below the surface to the mainland, have been tested by a number of bores, the strata passed through being clays, sands, and gravels, with bands of lignite and peat. Several bores were sunk to a depth of about 40 feet and all were found to contain salt water, and one, the depth of which is said to be 230 feet, met with

various beds of clay and peat, while at six different positions down to 118 feet brine beds were passed through, each bed containing a brine of greater density than the one above, a result no doubt due to the gravitation of the densest brines to the lowest levels. Table 4 is a record of the latter bore, giving details of the strata, density of brine, &c.

TABLE 4.—CASUARINA ISLAND BORE RECORD.

—	Thickness of Bed.	Total Thick- ness.	Depth of Waterbeds.	Density of Brine.	Per Cent of Solids.	Static Level*
	Ft. in.	Ft. in.	Ft. in.	B°		Ft. in.
Black soil .. ..	4 0	4 0	..	..	..	..
Red clay .. ..	0 6	4 6	..	..	..	..
Blue clay .. ..	24 6	29 0	20 4	4.5	4.6	8 0
Sand .. ..	9 3	38 3	34 6	7.75	7.8	12 0
Sand rock .. ..	1 0	39 3	..	..	..	..
Sand and gravel ..	5 4	44 7	..	..	..	..
Blue clay .. ..	0 6	45 1	42 8	7.75	..	12 10
Sand and gravel ..	16 0	61 1	..	..	..	..
Sand and coarse gravel ..	56 11	118 0	62 0	8.50	8.7	..
			70 0	9.25	9.4	13 8
			114 0	10.25	10.4	..

\* Bore was cased and as each flow was struck the water rose to within this distance of the surface.

Samples have been obtained from an old bore on this island which show from their attached labels that the bore penetrated a bed of lignite at 190 feet, of which the thickness has not been recorded. Some of the clays are slightly oil-bearing, and in this respect resemble clays about the Narrows, Miriam Vale, and Duaringa. Table 5 gives the analyses of the Casuarina Island brines together with others of well-known localities in other parts of the world.

TABLE 5.—ANALYSES OF NATURAL BRINES (FROM SPRINGS AND WELLS).

	Syracuse, N. Y.	Stafford, Eng.	Clinton, Ont.	Droitwich, Germ.	Schontseck, Germ.	Freid'shall, Germ.	Casuarina No. 2.	Casuarina No. 1.
Sodium Chloride ..	21·710	24·850	26·641	22·452	9·623	25·563	8·315	7·138
Magnesium Chloride ..	0·136	0·168	0·184	..	0·083	0·005	1·380	1·169
Potassium Chloride ..	..	..	..	..	..	..	..	..
Calcium Chloride ..	0·188	..	0·189	..	..	..	..	..
Sodium Sulphate ..	..	..	..	0·390	0·249	..	..	..
Magnesium Sulphate ..	..	0·090	..	..	0·012	0·023	0·822	0·746
Calcium Sulphate ..	0·505	0·429	0·275	0·387	0·339	0·437	0·397	0·359
Silica, Alumina, &c. ..	..	..	..	..	..	..	0·091	0·083
Magnesium Carbonate ..	..	..	..	0·034	..	..	..	..
Calcium Carbonate ..	..	0·010	..	..	0·027	0·010	..	..
Total solids ..	22·539	25·547	26·840	23·263	10·333	26·038	11·005	9·495
Specific gravity ..	1·170	1·197	1·207	1·176	1·070	1·202	1·076	1·064

### Meteorological Considerations.

Rainfall and the evaporation produced by the sun and wind are important factors to be considered in the manufacture of salt from sea water, and sites for works should be chosen, as a rule, where there is a minimum of rainfall and a maximum of solar and wind evaporation. Statistics showing only annual rainfall and evaporation are not of much use as a guide in fixing positions for operating, as it is necessary to know how much rain falls and how much water is evaporated in the different seasons of the year.

In the southern part of Australia the dry season is in the summer months, and in the northern parts in the winter months, so that for the south very effective solar evaporation takes place during the dry summer season, while in the north the winter evaporation is the more pronounced, more particularly at places far north and far away from the eastern coast—although the summer evaporation is also in excess of the summer rainfall. This is shown by the statistics given in Table 6.

TABLE 6.—AVERAGE RAINFALL AND EVAPORATION (AT STATIONS IN QUEENSLAND, VICTORIA, AND NORTHERN TERRITORY.)

	Brisbane.	Gladstone.	Rockhampton.	Port Alma.	Mackay.	Cooktown.	Normanton (approx.)	Burketown (approx.)	Beetoota.	Alice Springs, Cent. Aust.	Geelong, Victoria.	Melbourne, Victoria.
Annual—	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.
Rainfall ..	46.34	40.38	40.17	35.65	68.52	71.61	38.00	28.00	27.96	11.08	19.72	25.59
Evaporation ..	50.11	51.08†	51.08	51.08†	54.00*	56.00*	100.00*	100.00*	..	97.09	38.32†	38.32
Net evaporation ..	+3.77	+10.70	+10.91	+15.43	-14.52	-15.61	+62.00	+72.00	..	+86.02	+18.60	+12.73
November to April (6 months)—												
Rainfall ..	31.49	31.13	30.79	25.55	55.22	62.81	36.38	27.16	27.03	7.91	9.18	13.11
Evaporation ..	31.71	29.63†	29.63	29.63†	30.00*	30.00*	60.00*	60.00*	..	63.19	27.04†	27.04
Net evaporation ..	+2.22	-1.50	-1.16	+4.08	-25.22	-32.81	+23.62	+32.84	..	+55.28	+17.86	+13.93
Monthly rainfall ..	5.25	5.19	5.13	4.26	9.20	10.47	6.06	4.53	..	1.32	1.53	2.18
Monthly evaporation ..	5.28	4.94	4.94	4.94	5.00	5.00	10.00	10.00	..	10.53	4.50	4.50
Net monthly evaporation ..	+0.03	-0.25	-0.19	+0.68	-4.20	-5.47	+3.93	+5.47	..	+9.21	+2.97	+2.32
May to October (6 months)—												
Rainfall ..	14.85	9.25	9.38	10.10	13.30	8.80	1.62	0.84	0.93	3.17	10.54	12.48
Evaporation ..	18.40	21.45†	21.45	21.45†	24.00	26.00	40.00*	40.00*	..	33.90	11.28†	11.28
Net evaporation ..	+3.55	+12.20	+12.07	+11.35	+10.80	+17.20	+38.38	+39.16	..	+30.73	+0.74	-1.20
Monthly rainfall ..	2.48	1.54	1.56	1.70	2.22	1.47	0.28	0.14	..	0.53	1.76	2.06
Monthly evaporation ..	3.06	3.56	3.56	3.56	4.00	4.33	6.66	6.66	..	5.65	1.88	1.88
Net monthly evaporation ..	+0.59	+2.02	+2.00	+1.86	+1.78	+2.87	+6.39	+6.52	..	+5.12	+0.12	-0.18

\* Estimated.

† Rockhampton figures.

‡ Melbourne figures.

Geelong, in Victoria, is very favourably situated for the making of summer salt on account of having a slight net solar evaporation over rainfall in winter time, as shown in Table 6, in addition to which the excess of winter evaporation over rainfall prevents brines from becoming diluted where exposed in the open vats during the off-season.

In the north of Queensland the summer rainfall is far in excess of the southern winter rainfall, and, in consequence, if salt works were established in the north, this great rainfall might appear to be disastrous to the brines during the summer unless they were protected by covers. But this is not correct, the heavy rainfall being counterbalanced by a greater evaporation, which is probably much greater in some places (without even considering the winter evaporation) than the evaporation at the southern parts of Victoria for the whole of the year.

At Port Alma, in Keppel Bay, the annual net evaporation is 15.42 inches (*see* Table 6), which is less than that at Geelong by about 3 inches, but is greater than that at Melbourne by the same amount. At Cooktown in the dry winter season the net evaporation is almost equal to that at Geelong, but the rains in the wet season would no doubt dilute the brines if kept in vats without covers. With brines protected from summer rains the areas about Cooktown, Mackay, Port Alma, and Gladstone would offer very suitable sites for works, but otherwise they would not be so favourably situated as the salt works in Victoria.

The Normanton and Burketown figures in Table 6 are given approximately, but they show beyond a doubt that an enormous evaporation is going on along the shores of the Gulf of Carpentaria, and that it is spread over both the wet and dry seasons. This part of Queensland seems to be technically an ideal one for the manufacture of salt, because the evaporation must be almost continuous throughout the year.

It should be borne in mind, however, that while the rainfall figures for Normanton and Burketown are officially correct, the evaporation figures have been estimated, and are deduced from the statistics of other meteorological stations, consideration at the same time being given to the effects of prevailing winds, latitude, and distances from the eastern coast. The total annual evaporation at Normanton and Burketown is placed at 100 inches, and although this is nearly double the evaporation at Cooktown, it is very much less than that at Port Darwin, where some local observers consider the annual evaporation averages 140 inches. At Alice Springs, much further south than the latitude of

Normanton, the official statistics show 97 inches as the annual evaporation, of which 86 inches is net, the winter net evaporation being 30 inches and the summer 55 inches.

A comparison of the Gulf of Carpentaria figures with those of the eastern coast of Cape York Peninsula, as shown in Table 6, is decidedly advantageous to the former locality from a salt-producing point of view. During winter time the prevailing winds are from the south-east and reach the eastern coast charged with moisture from the Pacific Ocean. To a great extent these south-east monsoons or trade winds discharge their moisture about Cooktown, Mackay, and other parts of the northern coast, while along their north-westerly course inland localities receive less and less rain as their distance from the eastern seaboard becomes greater. For this reason the eastern side of the Peninsula is not so suitable for salt works as the areas on or beyond the western side. In addition to this is the fact that the south-east monsoons travel great distances overland after discharging their moisture near the coast before they reach water, and being dry they are in a perfect condition for the absorption of moisture when they reach the south-eastern and southern shores of the Gulf of Carpentaria.

No means have been available to test the salinity of the water in the Gulf, but factors regarding winds, rainfall, latitude, and the absence of currents there, and also the isolation of the Gulf from oceans, point to the sea water being abnormally dense. If this is so, then the shores of the Gulf would be still more favourable for salt precipitation with the water containing more salt per gallon than ocean water. A parallel with the Gulf in this respect might be made with the Red Sea, where the water contains over 3 per cent. of sodium chloride.

The rate of travel of the prevailing winds is undoubtedly an important point in connection with water evaporation, and from some experiments made it would appear that a wind travelling at the rate of 15 miles per hour evaporates five times as much water as the evaporation that goes on in a calm.

India may be compared with Cape York Peninsula on the question of rainfall and solar evaporation. Both areas are situated in the same latitude and both have about the same degree

of humidity, while the north-east monsoons of India have their parallel in the south-east monsoons of Queensland. The precipitation of rain takes place in India under identical conditions to those in Queensland, and in each case, after discharging their moisture on the land, the monsoons in trending towards the equator pass over a coastal area where the conditions are extremely favourable for the absorption of moisture from the sea.

On the east coast of India there is the equivalent of our coast to the north of Cooktown, and on the west of India we have a repetition of the conditions which prevail about the shores of the Gulf of Carpentaria. India makes over 800,000 tons of sea salt annually, all or nearly all of which is made on the west coast, and as this constitutes 60 per cent. of the whole salt production, the western coast of India must be a very suitable one for the solar evaporation process of salt manufacture. Comparisons may also be drawn with other parts of the world where similar climatic conditions prevail and where sea salt is being manufactured, and of these localities the principal ones are Rio Grande do Norte in Brazil, latitude  $12^{\circ} 5'$ , and Ecuador in latitude  $0^{\circ}$ .

The rise and fall of the tides are, of course, important factors to consider in determining the positions where solar salt works should be established, as the amount of sea water supplied to the ponds or vats will depend upon the height of the spring tides above the level of the natural salt pans. In this respect the conditions are satisfactory at a number of localities on the coast, particularly about the salt pans of Gladstone and Port Alma, where the rise of the tides is considerable, while in the Gulf of Carpentaria the tides are said to be sufficiently high to give a range of 2 feet or more over the salt pans about the mouth of the Norman River, the tides of February and March being particularly high. It is not known whether the shore areas to the west of this river and towards the Albert River, and also beyond, are suitable for the construction of extensive salt pans, but no doubt there are places in this little known part of the coast where the level of the land is such that considerably more than 2 feet of water would cover them at high water springs. In Table 7 is given a number of localities along the coast where the variations in the height of the spring tides have been recorded.

TABLE 7.—HEIGHT OF TIDES ON QUEENSLAND COAST.

Locality.	Height Variation. Spring.	Locality.	Height Variation. Spring.
	Feet.		Feet.
*Burketown ..	8—13½	Port Alma ..	13—16
*Normanton ..	8—13	Gladstone ..	10—12
Cooktown ..	7—10	Bundaberg ..	9
Townsville ..	8—12	Hervey Bay ..	10—12½
Mackay ..	12—16	Moreton Bay ..	5—6½
Broadsound ..	18—25†		

NOTE.—King tides usually occur in February.

\* One tide daily.

† These high tides are produced by the flood which sets southward meeting the flood which sets northward.

### Rock Salt Mining and Brine Pumping.

The usual operations in rock-salt mining consist in sinking a shaft to the bed of salt, and mining it as a seam of coal would be mined. Some of the deposits are very thick and extensive while others are very small, and in any system of working the salt consideration has to be given to the thickness of the seams and other local features. When the depth of the salt bed is very great, and occasionally even when shallow, recent practice is to sink bores instead of shafts, into which fresh water is forced, and when saturated with salt pumped out again and evaporated. If a connection can be established between two adjacent bores, the water is forced down one and returned up the other, the operation ultimately becoming a continuous one.

Various mechanical means are in vogue for bringing to the surface the artificial brine thus prepared, but probably the most effective is the method known as the air lift, in which a current of air is forced down a small pipe contained in a large delivery pipe, the air at the bottom mixing with the brine and forcing it up to the surface. Sometimes a method is adopted which is a combination of an air lift and a mechanical pump, and when conditions are favourable windmills are used.

### Working Lake Salt Deposits.

Natural deposits of salt on the floors of dried-up lakes are of common occurrence throughout the central areas of Australia, their thickness varying from less than an inch up to several feet. Where close to railway or other convenient means of transport, the salt in the dry season is scraped up and either used in the crude state or refined by recrystallisation.

In South Australia a source of large quantities of salt is Lake Fowler at Yorke Peninsula, where it is annually gathered and marketed. The operations consist in breaking up the salt bed, scraping it into heaps, and bagging it, the product in this crude condition being utilised for many purposes. Sometimes the salt is graded by crushing and sieving or made into a brine and recrystallised by artificial means.

The salt lakes of Western Queensland are very far distant from the eastern seaboard, and unless they subsequently prove to have some special merit in containing other minerals than sodium chloride, there is very little hope of their being worked as a source of salt. The composition of the salt from one of these, Lake Buchanan, is given in Table 3, the same table also containing the analyses of salt from other noted Australian salt lakes.

### **Salt from Sea Water and Brines.**

Several methods are employed in the manufacture of salt from sea water and from natural brines, but the commonly adopted processes are those in which the water is evaporated by solar heat or by direct heat or steam. Sometimes a method is used combining two of these processes, and occasionally wind is utilised in the concentration by passing the brine through open brushwood walls, which are sometimes 50 feet high.

A freezing method in cold climates is occasionally used in the preliminary stages of salt making. In this operation the sea water rejects most of the salt it contains as it freezes, and thus makes the remaining water much denser. The density of the water increases as the ice continues to form on the surface until it contains 23.6 per cent. of salt, the eutectic ratio, at which point the water and salt combine and freeze together, and further concentration has to be carried on by artificial means.

In solar evaporation a large area of flat land is required for the establishment of pans, ponds, or "gardens," and so situated as to be only inundated at very high tides. Many works have ponds aggregating a square mile or more in extent, but smaller areas are common. Rainfall and evaporation must be first considered in selecting sites for works, and the density of the sea water is also an important factor.

Some localities otherwise suitable may be useless on account of being close to rivers, the fresh water from which may considerably reduce the density of the sea water in the vicinity during the season most favourable for the making of salt. On the Queensland coast, Gladstone is very conveniently situated in this

respect, but the water at Port Alma would be subject to a freshening from the Fitzroy River, which drains an enormous area of country. The Gulf of Carpentaria occasionally receives flood water from the rivers falling into it from the east and south, but it appears that the Gregory River is the only stream flowing into it throughout the year. No doubt the Gulf water near the shore line becomes somewhat fresh during the wet season, but in the dry season, when the rivers are not flowing, it must be abnormally salt, as the evaporation is so very excessive and it is very shallow over a great portion of its area.

The character of the surface of the ground is also a matter of investigation. Sandy alluvium allows of a free percolation of water and is quite useless, the most desirable bed being a firm impervious silt or clay, a few inches of which is quite sufficient to act as a water-tight foundation. A sand cover to the clay makes a good base on which to precipitate the salt, and to a great extent prevents discoloration of the lower portion of the salt bed. Timber is sometimes used as a foundation, but the cost entailed in constructing wooden vats sometimes makes these installations prohibitive.

If the natural conditions are suitable for the formation of clay pans, much labour and expense is saved, and often a scheme will be unsuccessful simply because of the necessity of putting in timber flooring. Sometimes the establishment of the works will be warranted notwithstanding defective bottoms, under which circumstances a considerable loss of salt water is entailed and for which there is no remedy except the gradual cementation of the foundation material by the crystallisation of salt in its interstices, a remedy which may take years to become effective, particularly in the receiving ponds, where there is not much concentration of the sea water.

The pans or ponds are made into sections by the formation of embankments or dykes of clay about a yard in height, the width varying according to the additional use to which they are put, such as footpaths or roads. The sea water at high tide is taken in through a flood gate to a large reservoir, variably called receiving, tide, or intake pond, and then distributed into smaller reservoirs called concentrating, stock, or pickling ponds, the sea water gradually becoming denser by evaporation, and also cleaner by the precipitation of organic and other suspended matter, the operation taking about two weeks to accomplish.

The brine, for such it may now be considered, is removed

to another set of ponds, and as the evaporation by sun and wind continues and the density increases, a deposit of sulphate of lime (gypsum) is formed. The evaporation goes on until minute flakes of salt are formed on the surface of the brine, an indication that the saturation point ( $25^{\circ}$  to  $26^{\circ}$  Baume) has been reached, after which the brine is usually transferred to the crystallising pans or vats. Sometimes the salt is allowed to crystallise on top of the gypsum deposit, the two products being separated afterwards by mechanical means, but this method has a tendency to increase the amount of lime in the salt, which is an undesirable impurity.

As the evaporation continues, the salt crystallises on the bottom of the ponds, but where the brine reaches a density of  $28^{\circ}$  to  $32^{\circ}$  B. other constituents of the brine are ready to be precipitated with the remainder of the salt. As these constituents are detrimental to the salt, the solution, now termed mother liquor or bittern, is sent into a waste or slop pond, or is allowed to go back into the sea. In the former case supplies are drawn for subsequent treatment when any of the other constituents are required to be extracted.

The bittern still contains a high percentage of salt, and various methods have been tried whereby more of the salt is thrown out while keeping the other constituents in solution. One of these methods is to introduce some of the waste bittern into the brine in the crystallising pond, and thereby increase the density of the liquor to the saturation point and at the same time increase the charge of the other constituents more soluble than salt. This practice is said to cause a considerable reduction in the quantity of salt remaining in the bittern. Further reference to bitters and their constituents are made under a separate heading further on.

In some countries the evaporation of the brine is augmented by an arrangement of vats with "covers" or "aprons," the former being sliding roofs to protect the brines during the rainy season, the aprons being a more recent modification of this arrangement which permits the roofs being fixed with a very gentle slope and the brines made to flow over them. The aprons are a great improvement on the movable covers in enabling a much greater superficial area being utilised for sun and wind evaporation. The arrangement of covers or aprons, however, has not been adopted in Australia, and in the Gulf of Carpentaria would be almost superfluous, although on the eastern coast, if salt works were established there, they certainly would be of advantage in preventing the dilution of brines during the rainy

season in any system of solar evaporation. Indeed, this question of covers and the entailed capital outlay would be a serious one for consideration in the establishment of solar works either in the far distant Gulf of Carpentaria or at, say, Cooktown, where there is a net evaporation of 17 inches in the dry season (equal to Geelong), but where covers or aprons would be advisable to install on account of the abnormal rainfall in the wet months of the year.

### **Pond Area and Salt Harvesting.**

The total area and number of the ponds and their arrangement are matters depending on local circumstances. The porosity of the ground must be known, while statistical information bearing on the annual, seasonal, and monthly rainfall and solar evaporation is very necessary. A basis must also be established regarding the proposed annual output, and the possible, probable, and actual markets for the products.

Table 6 gives the statistics for a number of localities within and outside Queensland, and shows the net evaporation for both winter and summer. Burketown in the north of Queensland and Geelong on the southern shore of Victoria are places far apart, and as the salt harvesting season of the former would be in winter and the latter in summer they serve admirably for purposes of illustration and comparison.

The net solar evaporation at Burketown is approximately 72 inches per year and at Geelong 18.6 inches, so that 3 square miles of pond area at the latter locality would be equal to  $\frac{3}{4}$  of a square mile at Burketown, a proportion of 4 to 1. The area of the crystallizing ponds compared to the whole area is generally one tenth, and on this estimate, if the crystallising area at Geelong is 192 acres, *i.e.*, one tenth of 3 square miles, that at Burketown would require to be 48 acres. In each case the amount of sea water evaporated annually would be approximately 3,720,000 tons.

In estimating the quantity of salt contained in sea water a reference to Table 6 will show Geelong and Melbourne to have a fairly uniform annual rainfall, the number of inches during the winter months varying little from those of the summer months, while, on the other hand, the Carpentaria figures show heavy rainfalls in summer and very light ones in winter. The sea water density in Port Phillip would therefore vary only slightly with the change of seasons, while at Normanton and Burketown during the summer months the Gulf water would be expected to be somewhat fresher than in winter time, so that in Port Phillip

the density of the sea water would remain fairly constant all the year round while in the Gulf it is more saline in the winter time.

The net total summer evaporation of the Gulf, even though smaller than that of the winter, is enormously in excess of the total summer rainfall, from which it might be assumed, bearing in mind the Gulf's isolation and shallowness, that the total solids it contains would be 4.5 per cent. instead of 3.6 per cent.—the figures for the Pacific, as given in Table 1—and that, as stated previously, it probably contains 3 per cent instead of 2.6 per cent. of sodium chloride.

In 1 square mile of sea water 1 foot deep and containing 2.6 per cent. of salt there is 12,816 tons of this solid ingredient, and on this basis the amount of salt contained in 3 square miles of sea water 18 inches deep (as at Geelong) would be equal to that from  $\frac{3}{4}$  of a square mile 72 inches deep (as at Burketown), the quantity of salt being 57,672 tons; total solids, 84,837 tons. If the quantity of salt in the Gulf water be assumed to be 3 per cent. instead of 2.6 per cent., the quantity at Burketown in the assumed  $\frac{3}{4}$  square mile area would be—salt, 66,544 tons; total solids, 97,885 tons, a difference of 13,048 tons.

The yield of salt from sea water is based on the difference between the salt contents of the sea water delivered to the ponds and the salt contents of the bittern returned to the sea, provided leakage loss is not incurred from badly constructed vats or ponds. When sea water containing 3.5 per cent. of solids is evaporated to one-tenth of its bulk, the solid contents of the brine thus formed are increased to 35 per cent., the maximum quantity which can be carried in solution. Just at this point any sulphate of lime in the brine is thrown down as a solid, and pure salt is precipitated as the evaporation is continued, but when the reduction in volume to one-fifteenth is reached, other compounds begin to crystallize with the salt.

With the reduction in volume to one-fifteenth, the bittern would contain less than 35 per cent. of solids, while the proportion of solids other than salt would be increased, the composition of the solution being, approximately, 65 per cent. water, 20 per cent. salt, and 15 per cent. other solids. The total salt thrown down would be about 22 per cent. of the total solids, or a little over 50 per cent. of the salt in the sea water. As the Burketown figures show approximately 97,885 tons from a 3 per cent. solution, the yield from a  $\frac{3}{4}$  square mile pond area would be over 48,000 tons of salt.

The uppermost portion of the salt bed, a fair thickness of

which would be 5 or 6 inches, is always the purest and is always kept separate from the lower portion containing gypsum. If this mineral has been deposited with the salt, it can be removed from the friable salt by sieves, but it is always desirable to throw down the gypsum in a separate "lime" pond before sending the brine into the crystallising ponds.

After most of the salt has been removed and the brine has become saturated, it is often convenient to save more of the salt in a separate pond, but in this case there would be an admixture of magnesium chloride, sulphate of soda, and other compounds.

In some countries the solar evaporation of the sea water is not continued beyond the saturation point, the recovery of the salt being carried on by means of artificial heat in open pans (grainers) or in boilers (vacuum pans) the methods now usually employed in the recovery of salt from artificial brines. Another modification of this process is to redissolve the solar salt obtained and with it make a saturated brine, then to remove the impurities and recrystallise in grainers or vacuum pans.

In Victoria the gathering or "harvesting" season is in summer, usually during the month of February, when the rainfall averages only 1.24 inches, but the milling and refining continues throughout the year. In the Gulf of Carpentaria the month of September would be the most suitable, as this and the two preceding months have a rainfall averaging as low as .05 inches, although with so small a rainfall and so high an evaporation two harvests might be arranged, one in April, when the rainfall averages 0.89 inches, and the other in October, when the rainfall averages 0.32 inches.

The salt deposited in the crystallising ponds is at times loose and friable, but usually hard and compact, and in the latter case requires to be broken up with a plough. It is collected either in hand barrows or by means of travelling elevators and stacked on the roadways for subsequent removal, or else taken away at once to storehouses. Milling operations consist in screening and grading, and perhaps grinding the salt, the latter occasionally being necessary to release bittern enclosed in small cavities in the salt crystals. The salt is then delivered into vats filled with sea water or with a saturated brine made of pure salt and water, where it is washed free of magnesian salts or other bittern compounds. It is advisable, although not always convenient, to allow the salt to drain for several months to remove the more deliquescent impurities and thus improve its quality, otherwise it is dried at once in centrifugal mills and then heated

by steam or hot air in revolving dryers. It is next crushed in rolls and finally graded to the required degree of fineness for the market.

In some works the desire is to get the salt under cover as soon as possible and purify it by mechanical means during the milling process, while in other works there is a tendency to keep the salt in stacks or cocks for many months, or even years, as the absorption of moisture by the more deliquescent solid impurities causes their gradual elimination by a process of leaching. In some localities the salt hardens by long exposure and has to be taken to storehouses soon after it is harvested.

Recent improvements in other parts of the world tend towards the utilisation of greater evaporating surfaces for a given pond area by converting the movable covers into the aprons previously referred to. The slope of the apron is 1 inch in 100 feet and the depth about 3 inches. Their special advantage is in acting as evaporating pans in dry weather and as protecting roofs for the brines when rain is falling. If rain is expected, the aprons are emptied of brine at once into the vats below which is pumped back again when conditions are favourable. This arrangement of aprons above the vats is very suitable in areas where the solar evaporation is high and where rain falls at irregular intervals, and it would also allow, so far as Queensland is concerned, of evaporation being conducted nearly all the year round, as the highest evaporation is in the season when thunderstorms prevail. This may be seen from Table 6.

Brisbane, Gladstone, Rockhampton, Mackay, and Cooktown have each an evaporation of about 30 in. in summer time, but by the protection of the brines from rain by this system of aprons it is evident that (with the additional high evaporation of winter time) the results would be better in those places furthest north from Brisbane. This, of course, leaves out of consideration the question of local conditions as to transit, freight, labour, and suitability of site.

Mechanical labour saving devices in harvesting salt are very numerous and greatly reduce the cost of production. Elevators and belt conveyors are installed in some works, the power required being derived from petrol or steam at a central station. Occasionally the salt in the vats is lifted by manual labour on to a conveyor travelling across the vats and dumped on to the side, the whole arrangement being then shifted on rails to a position a little further on, where another stack of salt is to be formed.

Sometimes the salt before it leaves the conveyor is washed

with a spray of sea water to remove bittern, and although it is not always convenient to wash the salt at this stage—if it is to be washed at all—no doubt impurities are more easily removed when the salt is first handled than subsequently. An endless rope system of hauling the salt to the mill is at times adopted, trucks being used for delivering the salt on to a bucket conveyor which then takes it to the drying works.

Windmills have been found to be very effective for pumping purposes. In America they are permanently fixed in a position to catch the wind prevailing during the part of the year in which evaporation takes place. A central wooden shaft is shod at the base with an archimedian screw, and set in a pipe at an angle of about  $40^\circ$  from the horizontal. The vanes are at right angles with the central shaft, and as they revolve the mill becomes a direct acting centrifugal pump. There are a great number of these simple non-adjustable windmills in operation and evidently very suitable for the work. The shaft is about 20 feet long and the vanes, four to eight in number, extend about 8 feet from the centre.

### Artificial Evaporation.

*General Considerations.*—Sea water after being partly concentrated by the sun or wind is sometimes subjected to artificial evaporation as a final operation. Natural brines, such as those from springs, bores, or wells, and artificial brines made from rock salt or lake salt deposits are nearly always treated by artificial heat. A diagrammatic outline of the natural and artificial methods involved in the making of salt is given in Table 8, from which an idea may be formed of the operations described in this article.

All processes, artificial or natural, depend on the fact that if equal quantities of different chemical compounds held in the one solution are subjected to evaporation, there will be a certain order in which the compounds are deposited as crystals, this order depending on their relative solubility. The more common compounds and their order of solubility are given in Table 9.

TABLE 9.—ORDER OF SOLUBILITY OF SALTS IN WATER.

Parts in 100 at  $25^\circ$  C. ( $= 77^\circ$  F.)

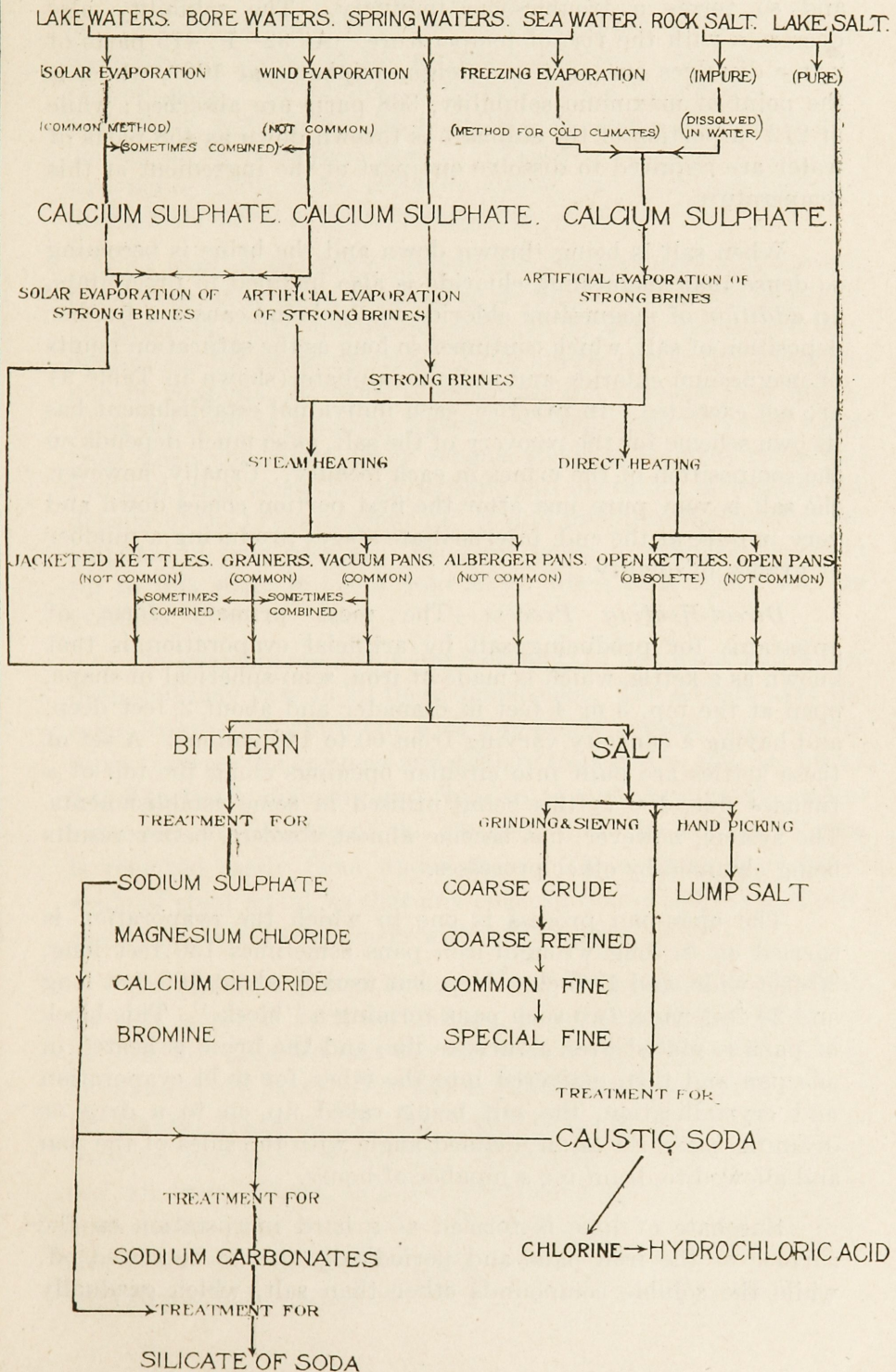
Sodium Iodide ..	184.2	Magnesium Sulphate ..	38.5
Potassium Iodide ..	148.0	Sodium Chloride ..	36.12
Magnesium Bromide ..	97.6	Sodium Sulphate ..	33.0
Calcium Chloride ..	91.0	Potassium Chloride ..	35.5
Sodium Bromide ..	77.0	Potassium Sulphate ..	10.75
Potassium Bromide ..	67.7	Calcium Sulphate ..	0.233
Magnesium Chloride ..	56.7		

QUEENSLAND GEOLOGICAL SURVEY PUB N°267

## SALT DIAGRAM

SHOWING

SOURCES, METHODS OF RECOVERY AND BY-PRODUCTS.



Calcium sulphate being the least soluble is the first to crystallise, but if the solution in which it occurs contains other compounds its solubility is affected to such an extent that it frequently precipitates only when the salt itself is precipitated, and so forms a troublesome impurity. The solubility also decreases with the rise of temperature. At 32° F. 415 parts of water dissolves one part of calcium sulphate; at 100°, which is the point of maximum solubility, 368 parts are absorbed; while at 212° a portion of the sulphate is thrown down as 458 parts of water are required to dissolve one part of the ingredient at this temperature.

When salt is being thrown down and the brine is becoming so dense that magnesium chloride is also inclined to precipitate, an *addition* of magnesium chloride to the brine causes a further deposition of salt, which continues so long as the saturation points of magnesium chloride and sodium sulphate (shown in Table 9) are not exceeded. In practice, each individual establishment has its own scheme for the recovery of the salt, as so much depends on the composition of the brines in each locality. Usually, however, the salt is very pure just after the first portion comes down and very impure at the end, intermediate stages producing a number of grades in quality.

*Direct-Heating Process.*—The most primary form of apparatus for producing salt by artificial evaporation is that known as a kettle, which is made of iron, semi-spherical in shape, open at the top, 3 or 4 feet in diameter and about 2 feet deep, and having a capacity varying from 60 to 140 gallons. A set of these kettles are built into circular openings along the top of a furnace flue, 100 kettles being utilised in some establishments. The system, however, has become almost obsolete, better results being obtained by other processes.

The open-pan process is one in which the evaporation is carried on in long wrought-iron pans sometimes 150 feet long, 30 feet wide, and 18 inches deep, but usually about 100 feet long and 20 feet wide, two such pans forming a "block." This block of pans is placed over a furnace flue and the brine is heated in one pan and then delivered into the other for final evaporation and crystallisation, the salt being raked up on to a drip or draining board set at an inclined angle with the sides of the pan and allowed to drain for a number of hours.

Sulphate of lime is formed as a hard incrustation on the surface of the iron pans and periodically has to be scaled off, while the soluble compounds other than salt, which gradually

accumulate as successive charges of brine are evaporated, have to be removed when the density of the bittern reaches a certain degree.

*Grainer Process.*—Jacketed steam kettles are a further improvement on the direct-heated kettles, but they also are being discarded in favour of the processes associated with grainer or vacuum pans. The method of evaporation in the grainer process consists in heating the brine in shallow open pans by steam instead of by the direct heat of a furnace, the pans being constructed of metal, wood, stone, or cement, and the steam conveyed through the brine by iron or copper pipes.

As most of the brine used in the grainer process is derived from wells, it must be clarified in settling tanks before going to the grainers, either quicklime, soda ash, or alum being used as a precipitant for the impurities. As an alternative to the precipitation by reagents, the brine is sometimes put through sand filters. Then the brine is generally warmed in deep tanks either by water from steam condensers or by exhaust steam or chimney gases and run into other steam-heated settlers, this operation increasing the density of the brine to about  $24^{\circ}$  B. and precipitating most of the sulphate of lime present. The time taken to prepare the brine up to this stage is about four days, when it is ready for the grainers.

The grainers are about 100 feet long, 12 feet wide, and 1 foot deep, but may vary in all these dimensions. The settlers have the same length and width but with a depth of several feet. Steam pipes traverse the grainers and settlers from end to end, are about 3 to 5 inches in diameter and from six to eight in number, and so arranged—in the case of the grainers—that the salt as it forms is removed easily from under them. These pipes are usually made of stout metal, so that any encrustation of sulphate of lime can be removed by hammers without damage.

Aprons are attached to the sides of the grainers, on to which the salt is raked as it crystallises, or otherwise end aprons or inclines are installed and the salt drawn out of the grainers by mechanical end rakes. The salt is allowed to drain on the aprons for several hours and is then removed to storehouses by wheelbarrows, trucks, or conveyors. Special care is required to free the salt from bittern, and this necessitates a washing with a hot brine made from pure salt. The product is then graded with sieves, and sometimes put through an air blast to remove the fine particles of sulphate of lime which are inclined to form.

Frequently the grainer is divided into back and front sections to enable the first-formed coarse-grained inferior salt, which contains traces of lime and magnesia compounds, being separated from the finer quality product. There is a demand for the coarse salt, and the grainer process of artificial evaporation is the only one by which it can be economically manufactured, the finer grade of grainer salt also being in greater demand than the very fine uniform grade made in vacuum pans. In some works when difficulties are experienced in getting a fine crystallisation such substances as oil, butter, or lard are thrown on to the surface of the brine to prevent the crystallisation becoming too coarse.

Successive charges of brine to the grainer and their continuous evaporation causes an accumulation of magnesium chloride in the grainer solution, and this has to be removed periodically. The removal must take place before the saturation point of the magnesium chloride is reached in the brine, otherwise the salt is contaminated with this and the other more soluble ingredients.

At the beginning of the evaporating operations the brine might contain about 10 per cent. of salt, which is increased to about 20 per cent. by the time it reaches the "draw" or final settler, where it is increased to about 25 per cent. It then enters the grainers and its density rises as the salt is precipitated, and when the total solids amount to about 35 per cent. of the solution it is removed as bittern.

*Alberger Process.*—In this modification of the grainer process the pans are circular in form and have revolving rakes on a central shaft, the salt being swept into a receptacle at the base. "Flippers" rotating on the shaft keep the surface of the brine free from coarse salt crystals, and effect the same purpose as oil or tallow. Continuous feeding of the brine is a feature of the process, and as the salt crystallises it is conveyed to a centrifugal pan for a preliminary drying and to a revolving steam dryer, perhaps 60 feet long, for a finishing operation.

*Vacuum Pan Process.*—This process is based on the fact that the removal of atmospheric pressure from the surface of a liquid reduces the temperature at which the liquid boils, and in salt works the application of this principle in what is called the vacuum pan process enables the brines to be evaporated at a low temperature. A system has been perfected by which steam generated in the vacuum of the first pan of a series is used in boiling the liquid in the second pan, the steam from the second pan being used in boiling the liquid in a third pan, and so on.

To effect this the vacuum pressure is lowered in each successive pan and the steam generated in the first pan is condensed to water in a coil passing through the liquid in the second pan. Here the vacuum is made lower so that the steam from it is of a lower temperature than the steam from the first pan which heats it, the third pan having a still lower vacuum and heated in the same way. The success of the process depends on the lowering of the pressure in a forward pan below that at which the water boils in a preceding one, each pan being an evaporator for the brine, a steam generator for the succeeding pan, and a condenser for the preceding one.

The steam entering the heating pipes of the first pan has a temperature of  $212^{\circ}$  F. and the pressure on the brine in the pan is reduced to a partial vacuum to allow steam to come off at about  $175^{\circ}$  F. The steam from this brine passes into the pipes in the second pan where the vacuum is so arranged that the steam comes off at about  $140^{\circ}$  F. In the third pan the vacuum is still lower and the temperature of ebullition about  $110^{\circ}$  F., while with a fourth pan the vacuum is made nearly absolute and the temperature further reduced.

In such a system a series of vacuum pans will evaporate about 4 lb. of water with 1 lb. of steam, the grainers evaporating only about 1 lb. of water to 1 lb. of steam. Where only one vacuum pan is used, the process is not so economical. A vacuum pan works in America is said to employ sixty men in the treatment of an artificial brine and makes 90,000 tons of salt per year.

The pans are generally 10 to 20 feet in diameter and from 30 to 50 feet high, but some are made 30 feet in diameter. They are made of steel, cylindrical in shape with rounded ends, the steam being conveyed through them by means of copper pipes. As the steam circulates the salt crystallises in the form of minute cubes and falls to the bottom. Special mechanical means are introduced to remove the salt as the precipitation proceeds, which is then delivered either to a centrifuge or a drying bin, where excess of moisture is taken out.

The most troublesome feature in working vacuum pans is the necessity of constantly cleaning the steam pipes from accumulations of gypsum. It is the usual practice to clean out with water once a day, and remove the scale by boring the pipes twice a week.

Recent modifications in vacuum pan methods consist in economising the steam, preventing excess of salt about the pipes, minimising the formation of gypsum crystals, removing the bittern, washing out the pans, and drying the salt, the latter improvement now being considered so effective that the salt may be sent to the steam dryers without any preliminary draining.

*Combination Processes.*—A supply of cheap fuel often makes it convenient or economical to use steam in the final operations when sea water is used as the source of the salt. The concentration to a saturated brine is usually carried on by solar evaporation or, as in cold climates, by a freezing process, and then crystallising the salt in grainers or vacuum pans.

Another process is that in which the fine crystallisation in the vacuum pan is converted into a coarser, non-flocculent form. To effect this the vacuum pan salt is put into a grainer with a brine, and as the evaporation continues, the salt is deposited on the minute crystals introduced, giving the product an appearance different to that of the ordinary salt produced in either the grainer or vacuum pan. By varying the quantity of the vacuum pan salt and the rate of evaporation, a number of grades are produced having a distinct superiority over the product made in the vacuum pans alone.

A further process is in evaporating the brine in steam-jacketed boilers, or in ordinary tubular boilers, the density being reduced from 9° to 15° B. It is then filtered through a sand bed and run into settlers, and finally evaporated in grainers.

TABLE 10.—ANALYSES OF COMMERCIAL SALT.\*

	Lochiel, Fine.	Castle Co., S.A. Extra Fine.	Saltville, U.S.A.	Lymm (Cheshire) England.	Utah, U.S.A. Refined.	Casuarina, Coarse.	Geelong, V. Refined "Mermaid."
	%	%	%	%	%	%	%
Sodium Chloride .. ..	98.21	98.50	98.54	99.68	99.43	93.72	96.38
Magnesium Chloride .. ..	0.36	0.34	..	0.10	..	..	0.14
Calcium Chloride .. ..	..	..	0.01	..	..	..	..
Potassium Chloride .. ..	..	..	..	..	..	..	0.15
Sodium Sulphate .. ..	0.16	0.42	..	.12	trace	..	2.77
Magnesium Sulphate .. ..	..	..	..	..	trace	..	..
Calcium Sulphate .. ..	0.97	0.34	1.44	..	0.37	1.88	0.43
Moisture .. ..	..	..	..	.07	trace	3.44	..
Silica, Iron, Alumina, &c. ..	0.01	..	..	.03	..	..	0.14
Moisture at 212° .. ..	0.29	0.40	..	..	0.18	..	..
Totals .. ..	100.00	100.00	99.99	100.00	99.98	99.04	100.01

\* See also Analyses of Lake Salts—Table 3.

### Salt from Natural Brines.

The recovery of salt from natural brines was once a very important industry, but is now subordinated to methods of treating rock salt deposits by which water is forced into them and pumped back as saturated brine. The natural brines vary much in their densities, and it has been observed that the deeper they occur below the surface the more salt they carry in solution. Some natural brines contain over 26 per cent. of salt, as shown in Table E, but many are utilised which contain considerably less than this percentage.

The brines obtained from the upper stratum in the bores on Casuarina Island, at the mouth of the Fitzroy River, have a density slightly greater than sea water (*see* Table 4), but the density becomes greater as the depth increases, until at 29 feet the percentage of solids is 4.6, while at 118 feet the percentage increases to 10. Whether brines of greater density exist below this level is not known, but the bore specially sunk to test the brine was discontinued at 230 feet because the supply and density of what was found was considered quite satisfactory by those who were then concerned in manufacturing salt.

Pumps working for ten hours per day lifted 40,000 gallons of brine, and the level of the brine at 114 feet which rose to within 13 feet 8 inches of the surface when first tapped could not be lowered further than 18 feet 2 inches from the surface.

The natural clay pans on Casuarina Island and also on the adjacent mainland are of large extent, and apparently well suited as sites on which to construct ponds or vats for the evaporation of brines. In the experimental work on salt making on the island about  $2\frac{1}{2}$  acres were enclosed as ponds in which the preliminary evaporation took place, and when the gypsum started to come down the brine was then pumped into crystallising pans. After the salt was deposited, the bittern was allowed to go to waste and the product collected into heaps and drained, subsequently being bagged as coarse salt. The process was very crude, but such as it was 1,300 tons of salt was produced, which shows very effectively that the salt could be manufactured from the brine in the open even though in an area where the net evaporation for the dry winter months was only 11 inches.

TABLE 11.—ANALYSES OF TOTAL SOLIDS IN ARTIFICIAL BRINES.

	Saltville, U.S.	Saginaw, U.S.	Cheshire, Eng.	Dièze, France.	Clinton, Ontario.	Freid'shall, Germ.
Sodium Chloride ..	24.06	17.51	25.69	14.42	26.64	25.56
Magnesium Chloride ..	..	1.07	0.06	..	0.18	0.01
Calcium Chloride ..	0.01	2.64	0.04	..	0.18	..
Magnesium Sulphate ..	..	..	..	0.50	..	0.02
Calcium Sulphate ..	0.53	0.10	0.41	0.28	0.27	0.44
Calcium Carbonate ..	..	..	..	..	..	0.01
Magnesium Carbonate ..	..	..	0.10	..	..	..
Total solids, per cent.	24.60	21.32	26.30	15.20	27.27	26.04
Sp. gravity of brine ..	1.189	1.159	1.204	1.109	1.210	1.202

TABLE 12.—ANALYSES OF TOTAL SOLIDS IN BITTERNS.

	San Mateo, Cal.	Mt. Eden, Cal.	Alvarado, Cal.	Michigan.	Mediterranean Sea.	Pomeroy, Ohio.	Geelong.
Sodium Chloride ..	62.48	19.24	68.66	83.40	30.50	1.18	39.2
Magnesium Chloride ..	20.00	46.77	1.20	3.33	41.35	28.29	29.1
Potassium Chloride ..	4.80	7.60	19.07	1.15	..	1.08	6.2
Calcium Chloride ..	..	..	..	12.02	..	65.95	..
Magnesium Sulphate ..	10.44	25.00	10.24	..	18.54	..	25.1
Potassium Sulphate ..	..	..	..	..	5.71	..	..
Calcium Sulphate ..	1.23	0.46	0.17	0.10	..	1.30	..
Potassium Bromide ..	..	..	..	..	..	..	0.4
Magnesium Bromide ..	1.05	0.93	0.66	..	3.90	2.20	..
	100.00	100.00	100.00	100.00	100.00	100.00	100.0
Total solids, per cent. ..	34.45	38.95	33.12	31.83	40.11	56.02	..
Specific gravity of brine ..	1.26	1.29	1.25	1.24	1.30	1.40	1.23

### Bitterns.

The composition of the bitterns produced at the termination of the salt extraction has a considerable variation, due partly to the original constituents of the salt water operated upon and partly to the treatment which the brine receives. The contents usually consist of a preponderance of salt with smaller quantities of magnesium chloride, and still smaller quantities of other chlorides and various sulphates and bromides.

Magnesian chloride is sometimes manufactured as a by-product, and if a high percentage of potash salts is present the bittern is treated for these compounds, while in one central works the liquor from a number of individual works may be

treated for its bromine and other contents. The analyses given in Table 12 show a great variation in the composition of bitterns, and the analysis of the San Mateo bittern from the works on the shores of San Francisco Bay, California, may be taken as typical of the product resulting normally from the solar evaporation of sea water, while the analysis given of the bittern at the Mount Eden works in California indicates that a process is used in which magnesium chloride is added to the brine to throw out more of the salt.

The treatment of bittern for by-products is only carried out when under specially favourable circumstances, and no doubt immense quantities of the liquid are allowed to run to waste because the cost of treatment would be excessive compared to the value of the saved product. So far as Queensland is concerned, there is only a limited demand for magnesium chloride, but this would certainly be increased in making sorrel or magnesium cement if the compound could be produced cheaply, while a small demand would exist for bath salt made by simply evaporating the bittern to dryness.

### Associated Industries.

*Calcium Sulphate (Gypsum).*—This compound is the one first formed during the evaporation of sea water and brine, and being very insoluble, easily separates from the salt. As a by-product its value is generally very low from the fact that it occurs as a mineral in beds of great extent and in a very pure form. Gypsum deposits in Eastern Queensland are very small, while the deposits known in the Western districts are practically valueless in being situated so far from railway communication. Reference is given in the Report on North-Western Queensland\* to the extensive occurrence of salt on the Mulligan River near the western border.

*Sodium Sulphate (Salt Cake).*—This is precipitated from the bittern as the brine becomes denser and after a certain percentage of the salt has been thrown down, care being required in eliminating the compound to prevent its forming an impurity in the salt. It is produced in a large way either by direct treatment of the salt with sulphuric acid or by a process in which sulphur fumes, oxygen, and steam is applied, the latter method being much in vogue. It occurs in nature as Glauberite, but seldom pays to work because it is obtained as a cheap artificial product. It is used principally in the manufacture of carbonate of soda (soda ash), and is also applied to glass-making, dye manufacture, and as a medicine under the name of Glauber Salts.

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\* North-Western Queensland. Geological Notes on the Cloncurry-Camooweal-Burketown-Boulia Area. By B. D., Brisb. By Auth. 19-0. Geol. Surv. Pub. No. 265.

*Magnesium Chloride.*—In all bitterns this compound forms a large proportion of the solid contents and is precipitated by a simple evaporation process. It has a limited use in the manufacture of sorrel cement, the oxy-chloride of magnesia, a compound of magnesia hydrate and chloride, for which purposes it must be free from lime.

*Calcium Chloride.*—This is sometimes a constituent of natural and artificial brines and lake waters, but does not occur in sea water (*see* Tables, 1, 5, and 11). When it is present in bitterns it may be isolated after the compounds mentioned above have been removed. It is mainly obtained as a by-product in the manufacture of carbonate of soda from salt, the chlorine in the latter being made to combine with ammonia to produce ammonium chloride and sodium hydrate, which, with the introduction of lime, forms calcium chloride. There are many uses for the compound in industrial and experimental chemical operations, but none would absorb large quantities.

*Bromine* exists in some bitterns in very small quantities and probably in the form of sodium or magnesium bromide (*see* Table 11). Its presence in salt is considered to be indicative of a marine origin for the deposits in which it occurs, while its absence is said to show that the deposits have been formed in inland lakes.

It is made by distilling bittern with sulphuric acid and potassium chlorate, the bromine being released as gas and afterwards condensed to a liquid form and collected in water. An electrolytic method is also used to generate the bromine, the operation sometimes taking place before the salt is thrown down, but usually afterwards.

The demand for bromine for the manufacture of photographic and other chemicals is somewhat small, and much larger quantities could be produced from some of the waste bitterns if other uses could be found for the element.

*Iodine* is another bittern product, which, however, can be produced from the Chilian nitre deposits so cheaply and in such quantities that its extraction as a salt by-product cannot be encouraged. It is precipitated from the bittern by sodium bisulphide and then retorted, a sublimate formed being made up of delicate crystals.

*Sodium Carbonates and Caustic Soda.*—Soda ash may be prepared by subjecting the salt brine to electrolysis to form the metal sodium, which is converted immediately afterwards into

the hydrate (Caustic Soda). The solution is then charged with carbon dioxide and steam to precipitate bi-carbonate of soda, and this on calcining produces the carbonate (soda ash). Another process consists in adding ammonia to the brine and then charging it with carbon dioxide, the products being a precipitate of bi-carbonate and a solution containing ammonium chloride. A further process is that known as Leblanc's, in which salt cake is heated in a furnace with limestone and charcoal to make "black ash," a mixture of sodium carbonate and calcium sulphide, from which the carbonate is extracted by water.

This is an exceedingly important industry and absorbs large quantities of salt and limestone, but requires a large capital for plant and very cheap power.

*Sal Soda* (hydrated carbonate; washing soda; crystal soda) is made by dissolving soda ash in hot water and allowing the solution to cool, the crystals of soda which form containing about 60 per cent. of water.

*Potash*.—Bitterns can be treated for any potash they may contain by introducing carbonate of soda to remove the magnesium as a carbonate, and then evaporating the solution containing sulphates and chlorides for the recovery of the potash.

*Silicate of Soda* (Water Glass).—Two methods exist for producing this compound, one by fusing the carbonate or sulphate of soda with powdered silica, either as quartz-flint or, preferably, diatomaceous earth, the other by digesting the same siliceous ingredients with a hot solution of caustic soda under a pressure of four or more atmospheres, the solution then being evaporated to the consistency required. It is used largely in soap making and as an egg preservative, and to a limited extent in dyeing, enamelling, and calico printing.

*Chlorine* forms as an electrolytic by-product gas in making soda ash or caustic soda from salt with sulphuric acid, and in a dry condition combines with lime to form an oxy-chloride, the substance commonly used as Bleaching Powder and as a disinfectant.

*Hydrochloric Acid* is another indirect by-product of salt, and is formed in the making of sodium sulphate. The chlorine evolved as a gas in the process is mixed with steam and then condensed to form the acid.

*Epsom Salts* is another indirect salt by-product, but it is more conveniently manufactured direct from magnesia or magnesium carbonate.

### Commercial Salt Grades and their Uses.

A number of grades in salt are put on to the market and depend first on quality and next on size of grain. They are not standardised, however, and each salt-making company suits its own fancy as to the names given to the various qualities. In a general way they may be classified as follows:—

*Lump (rock) salt.*—For cattle and sheep licks.

*Coarse crude.*—Mesh,  $\frac{1}{4}$  to  $\frac{1}{8}$  inch; rock salt or sea salt not refined—as it comes from the mines, lakes, or vats. Used as cattle and sheep licks, for salting hides, freezing mixtures for ice creams, &c.; fertilisers; soapmaking; glassmaking; glazing pottery, &c.; enamelling; pickling; ice thawing on railways and tramways; processes of gold, silver, and copper recovery; and potash recovery in the manufacture of portland cement.

*Coarse refined.*—Mesh,  $\frac{1}{4}$  to  $\frac{1}{8}$  inch. Special care is taken in freeing brines from impurities before crystallising, and subsequently drying the salt in stoves with either steam or hot air to remove moisture and the fine dusty calcium sulphate which separates from the salt as the moisture is removed. Used in meatworks; pickling; manufacture of caustic soda and other sodium compounds; bacon, ham, meat, and fish curing; bread-making, &c.

*Common fine.*—This is a refined salt with a grain small enough to pass through a 40-mesh sieve. Used commonly for domestic purposes; also for most purposes enumerated under “coarse refined,” and for packing hams and bacon required for hot climates.

*Special fine.*—1, Cheese salt (20-mesh); 2, dairy salt (30-mesh). Adapted for use where rapid solution is necessary and where uniformity of salting is specially required. If magnesium chloride is present in even minute traces the tendency of the salt is to deliquesce, and some chemists contend that it is entirely due to this impurity that salt absorbs moisture at all. Traces of calcium sulphate are also bad, particularly where the salt comes in contact with moisture, as in bacon or meat, because the impurity is inclined to form an incrustation on the surface as evaporation proceeds.

*Castor Salt* is a table salt mixed with a small proportion of magnesium carbonate or starch, the object of introducing these ingredients as “fillers” being to absorb moisture and thus keep the salt in a dry granular condition.

### General Notes.

#### FUEL FOR SALT MAKING.

In artificially making salt a process often appears to be applicable on first consideration that subsequently is found to be unsuitable because the cost of fuel is too high. Sometimes exhaust steam from a large works, such as an electric power plant, or waste heat from coke ovens or furnaces, are used to great advantage, and also waste timber from sawmills. All kinds of fuel are applicable to the evaporation of brines either in generating steam or making hot air, and lignites or other inferior coals are utilised. In Queensland there are enormous supplies of bituminous coals, but railway or ship freights would be a serious consideration in their utilisation.

The Dawson-Mackenzie coal of Central Queensland has been suggested as suitable for a saltworks fuel, notwithstanding the distance the field is away from the coast, as it is to a great extent non-coking and is said to contain from 1.8 to 2.1 per cent. of nitrogen. It could be burned in a by-product recovery oven, and the product might yield sufficient sulphate of ammonia to pay for the cost of freighting the coal from the mines to the coast. The suitability of Queensland coals for by-product recovery has not been closely investigated, and possibly coals from other fields might be found which would answer the purpose.

Fuel efficiency is difficult to estimate, but it appears that under similar conditions 1 ton of good coal will produce from a brine 1 ton of salt if direct-heated kettles and pans are used, and 1.25 tons if grainer pans are used, and 1.4 tons with vacuum pans. The actual quantities produced will depend on the amount of water evaporated, the construction of the pans, the quality of the coal, and the altitude of the locality where the operations are conducted, the latter factor having relation to the boiling point of the brines.

#### LIMESTONE FOR SODA MANUFACTURE.

In the manufacture of some of the by-products from salt one of the necessary ingredients is carbonate of lime, this being used in the manufacture of the carbon dioxide required in making ammonium carbonate in the soda ash process. The limestone is required to produce the calcium hydrate used in convert-

ing into free ammonia the ammonium chloride formed by the reaction between the ammonium carbonate and the salt, the chlorine combining with the lime to form calcium chloride.

In a soda works the necessary amount of limestone, which must be very pure, is nearly as large as that of the salt itself, and certainly greater than the quantity of coal.

In Queensland several limestone areas exist where almost chemically pure carbonate of lime can be obtained, amongst which might be mentioned Raglan and Ambrose, between Gladstone and Rockhampton; Silverwood, Gore, and Texas in the Stanthorpe District; and Mundubbera beyond Gayndah; all of which contain deposits averaging in composition between 54 and 56 per cent. of lime and an exceedingly small percentage of impurities.

#### SALT FOR COPPER EXTRACTION.

The use of salt has been suggested as a reagent in the extraction of copper from low-grade Cloncurry copper ores provided the article is obtainable cheaply, as would be the case by the evaporation of sea water on the shores of the Gulf of Carpentaria. No doubt the treatment of low-grade copper ores in this part of the State is much handicapped by unavoidably high costs, and the introduction of a process for utilising salt in a chloridising furnace to produce copper chloride for electrolytic extraction should considerably reduce expenses. The quantity of salt required would be very great, as 5 per cent. or more is necessary to mix with the ore to be roasted, while on the other hand the cost of the salt would be very low. In electrolytic extraction the copper in the form of chloride is better under most conditions than a sulphate, because the chloride does not require the same amount of electrical energy as the sulphate for its reduction to the metallic condition.

#### USEFUL SALT DATA.

The specific gravity of salt is taken to be 2.2, but it varies from 2.1 to 2.6.

One cubic foot of distilled water weighs 62.425 lb.

One cubic foot of sea water weighs 63.940 lb. (3.5 per cent. solids).

One cubic foot of salt (Sp. Gr. 2.2) weighs 137.335 lb.

One cubic foot of sea water (3.5 per cent. total solids—2.6 per cent salt) contains 1.030 lb. of salt and .485 lb. of other solids = 1.515 total solids.

100 cubic inches of sea water (as a column 100 in. by 1 in. by 1 in.) contains .0596 lb. of salt and .0280 lb. of other solids = 1.106 cubic in.

A thickness of 1 in. of salt in a deposit represents an evaporation of 91 in. of sea water.

One acre of sea water 1 ft. deep (66 ft. by 660 ft. by 1 ft.) has a capacity of 43,560 cubic ft.

One acre of sea water 1 ft. deep (43,560 sq. ft. by 1 ft. by 1.030 lb.) contains 44,866.8 lb. (20.025 tons) of salt and 21,126.4 lb. (9.436 tons) of other solids = 29.461 tons of total solids.

One acre of salt 1 in. deep contains 222.544 tons of salt (Sp. Gr. 2.2).

One square mile of sea water 1 ft. deep contains 12,816 tons of salt and 6,039 tons of other solids = 18,855 tons of total solids.

One imperial gallon (.1605 cubic ft. or 4.541 litres) of sea water contains 1,157.2 grains (= .1653 lb. or 75.89 grammes) of salt.

One imperial gallon of distilled water weighs 10 lb.

One litre of sea water contains 16.492 grammes (254.513 grains or .036 lb.) of salt.

One litre = .0353 cubic ft. = .2202 gallons.

One barrel of salt weighs 280 lb. Eight barrels weigh 1 ton.

One bushel = 8 gallons = 1.284 cubic ft. = 36.628 litres.

One bushel of salt weighs 176.338 lb. (according to some standards).

One gramme = 15.4323 grains.

One grain = .0648 grammes.

One salimeter degree =  $0.26^{\circ}$  Baume =  $0.35^{\circ}$  Twaddell = 0.265 per cent. of salt in solution.

An increase of  $1^{\circ}$  Baume in specific gravity (density) indicates an increase in 1.0192 percentage of salt in solution.

Every increment of  $\frac{0.265}{2}$  per cent. of salt in water, *i.e.*, 0.1325, increases the specific gravity to the extent of .000875.

Six persons, it is estimated, consume one barrel of salt in one year = 46.66 lb. each, or a little less than 1 lb. per week.

### World's Production of Salt.

The United Kingdom has by far the largest recorded total production of salt, and the United States the largest annual production during recent years, some of the yields of the latter being more than double, and in one year nearly three times, that of the United Kingdom.

In value the United States production since 1883 is greater than that of the United Kingdom since 1860, while in recent years the annual value of the United States production is in no case less than three times that of the United Kingdom. The United Kingdom production is fairly uniform from year to year, while in the United States the 1911 yield was 3,897,997 tons and that of 1916 reached 5,681,166 tons, the increase being attributed to the wonderful advance in the mechanical methods of recovering salt from brines. These results are shown in Tables 13 and 14. Next in importance in total salt production is Russia, then comes Germany, India, France, Spain, Japan, Italy, Austria, and Hungary. In recent years the value of Germany's production almost equals that of the United Kingdom, with Russia, France, and India next in order of value.

In the countries enumerated in Tables 13 and 14 the average value of salt per ton varies considerably. In Egypt it is estimated to be just over 3s., while in Hungary, where the industry is a Government monopoly, the value is £7 9s. 8d. per ton. Where the manufacture of salt is rapidly increasing and where the salt product is utilised in other secondary industries, the value per ton is low, a result entirely due to improved methods of manufacture.

Commonwealth salt statistics are only available for South Australia so far as actual production is concerned, but an estimate has been made of the production of Victoria. The Victorian Government Statist states that the returns from the industry cannot be made public as practically only one company is operating in Victoria and the publication of the returns would reveal the business of the firm. However, in the statistical returns the necessity of showing some value for the production is apparent, and the salt values are bracketed with "building stones."

TABLE 13.—TOTAL PRODUCTION OF SALT BY PRINCIPAL COUNTRIES.\*

Country Producing.	Years of Production.	Production.	Value.	Approx. Value per ton.
		Tons.	£	£ s. d.
United Kingdom ..	1860—1916	108,533,709	42,938,097	0 7 11
United States ..	1883—1916	85,593,662	46,380,693	0 10 10
Russia ..	1830—1914	63,500,713	†31,757,100	0 10 0
Germany ..	1862—1912	50,922,227	35,678,700	0 14 0
India ..	1881—1917	38,667,306	15,089,715	0 7 9
France ..	1873—1913	36,505,442	12,915,135	0 7 1
Spain¶ ..	1871—1917	16,530,993	†6,718,900	0 8 1
Japan ..	1890—1912	†15,378,300	†19,903,600	1 5 3
Italy ..	1860—1915	15,042,526	6,245,316	0 8 4
Austria† ..	1869—1913	13,023,820	\$81,994,308	6 5 11
Hungary‡ ..	1867—1913	7,087,483	†\$53,029,200	7 9 8
Aden† ..	1894—1917	2,237,295	793,554	0 7 1
Canada ..	1886—1917	2,054,543	2,199,788	1 1 5
Portugal†† ..	1880—1912	1,795,872	550,077	0 6 1
Tunis ..	1886—1912	†985,200	†236,400	0 4 9
Turks and Caicos Islands	1896—1912	788,122	343,406	0 9 8
Egypt   ..	1907—1912	664,505	**103,500	0 3 1
Algeria ..	1886—1913	649,805	571,278	0 17 7
Greece‡ ..	1887—1915	640,917	2,315,210	3 12 3
Formosa † ..	1901—1912	542,521	262,967	0 9 8
Union of South Africa	1885—1916	529,766	979,373	1 17 0
Bosnia & Herzegovina	1885—1914	414,623	†143,800	0 6 11
Ceylon ..	1882—1912	375,474	1,168,436	3 6 9
Peru† ..	1900—1915	327,097	427,988	1 6 2
Chile ..	1895—1912	234,663	†673,500	2 17 4
Dutch West Indies   ..	1897—1912	197,907	100,783	0 10 2
Phillipine Islands ..	1909—1916	151,990	457,019	3 0 1
Siam ..	1905—1910	100,171	112,837	1 2 6
South Australia ..	1903—1917	859,465	627,097	0 14 7
Victoria ..	1911—1917	†280,000	292,000	1 8 6

\*The statistical information has been compiled from the following sources, viz.:—Mineral Industry; Mineral Resources; and Engineering and Mining Journal (United States); Mines and Quarries (United Kingdom); Geological Survey (India); Statistique de l'Industrie en France et Algerie (France), &c.

† Estimated in part.

‡ Government monopoly.

§ High values for Austria and Hungary are due to Government monopoly and high taxation.

|| Exports.

¶ Part production, part exports.

\*\* Estimated export values.

†† Statistics very incomplete; 22 years missing.



TABLE 14.—*continued.*TABLE 14.—ANNUAL SALT PRODUCTION BY PRINCIPAL COUNTRIES—*continued.*

Country Producing.	Year of Production.						
	1911.	1912.	1913.	1914.	1915.	1916.	1917.
Canada ..	Tons 81,671	84,868	89,992	95,570	107,053	118,663	123,847
Formosa ..	Value £ 92,292	95,746	102,350	102,843	125,047	149,511	218,290
Turks and Caicos Island	Tons 67,712	62,004	..	..	..	..	..
South Africa Union	Value £ 24,451	20,836	..	..	..	..	..
Greece ..	Tons 45,370	43,217	..	..	..	..	..
Peru ..	Value £ 19,503	18,603	..	..	..	..	..
Ceylon ..	Tons 36,159	37,364	*37,200	40,290	45,104	..	..
Bosnia and Herzegovina	Value £ 61,160	63,096	*64,100	62,000	81,634	..	..
Philippine Islands	Tons 27,826	28,165	..	..	..	..	..
South Australia ..	Value £ 129,837	134,265	..	..	..	..	..
Victoria (estimated)	Tons 24,474	22,293	23,948	25,523	25,322	..	..
	Value £ 21,577	16,305	*23,900	*25,500	*25,300	..	..
	Tons 86,309	13,839	..	..	..	..	..
	Value £ 21,262	55,168	..	..	..	..	..
	Tons 7,627	21,561	23,794	22,758	..	..	..
	Value £ 18,043	7,890	*8,600	*8,200	..	..	..
	Tons 57,291	18,844	19,191	19,784	22,144	24,358	..
	Value £ 65,000	59,845	59,896	61,458	62,500	77,343	..
	Tons 40,600	64,300	65,000	65,000	64,000	66,400	46,858
	Value £ 40,000	40,187	48,750	48,750	80,000	83,000	93,716
	Tons 26,000	40,000	40,000	40,000	40,000	40,000	40,000
	Value £ 26,000	26,000	30,000	30,000	50,000	50,000	80,000

\* Estimated.

TABLE 15.—EXPORTS OF SALT BY PRINCIPAL COUNTRIES.

Country Exporting.	Year of Exportation.						
	1911.	1912.	1913.	1914.	1915.	1916.	1917.
United Kingdom	Tons Value £	548,496 453,860	533,524 472,575	494,042 457,056	..	..	..
Spain	Tons Value £	543,320 †137,400	555,129 140,400	501,231 127,300	.. 479,863	418,306 106,200	.. 88,100
Germany	Tons Value £	423,340 ..	425,555 ..	35,014 40,174	..	..	..
China	Tons Value £	110,825 153,449	..	..	..	..	..
Egypt	Tons Value £	120,849 18,888	86,853 82,299	93,615 101,693	.. 125,123	115,429 296,364	..
Asiatic Turkey	Tons Value £	.. ..	72,266 66,920	62,285 60,896	..	..	..
United States	Tons Value £	55,723 *87,198	62,758 107,332	73,478 122,095	71,852 127,885	81,262 131,035	..
Turks and Caicos Islands	Tons Value £	43,217 18,603	..	..	..	..	..
Aden	Tons Value £	.. ..	124,908 115,955	153,928 146,790	102,286 108,995	96,465 169,586	..

TABLE 16.

TABLE 16.—IMPORTS OF SALT BY PRINCIPAL COUNTRIES.

Country Importing.	Year of Importation.						
	1911.	1912.	1913.	1914.	1915.	1916.	1917.
India ..	551,560	551,689	590,431	562,018	519,523	446,069	341,986
Value £	541,600	541,700	570,457	560,657	677,972	1,260,295	1,360,093
British East India	162,755	134,657	..	..	..	..	..
Value £	88,453	73,797	..	..	..	..	..
Canada ..	111,026	124,738	128,967	127,362	122,756	135,007	152,509
Value £	90,858	101,240	117,967	112,684	107,818	144,757	226,709
United States ..	123,000	121,733	134,465	116,743	109,889	108,543	..
Value £	78,767	75,347	87,766	80,365	76,349	71,373	..
West Coast of Africa	50,864	55,478	58,509	..	..	..	..
Value £	79,106	88,118	100,385	..	..	..	..
Sweden and Norway	42,381	46,719	46,722	..	..	..	..
Value £	29,669	31,861	23,630	..	..	..	..
Russia ..	35,023	24,594	29,876	..	..	..	..
Value £	25,103	16,760	22,659	..	..	..	..
Australia ..	30,986	18,258	18,623	..	..	..	..
Value £	29,419	18,263	20,707	..	..	..	..
Germany ..	28,607	17,604	21,083	..	..	..	..
Value £	22,538	25,619	..	..	..	..	..
Belgium ..	14,759	16,125	25,925	..	..	..	..
Value £	11,295	11,154	18,210	..	..	..	..
Brazil ..	10,079	12,202	10,533	..	..	..	..
Value £	9,097	7,817	14,216	..	..	..	..
Union of South Africa	9,299	8,102	7,612	..	..	..	..
Value £	..	8,059	..	..	..	..	..

China's production of salt is unknown, although the accompanying tables show that before the war considerable quantities were exported, while Japan apparently has not been exporting, although she is the eighth largest producer in the world. India's production is very great—the sixth largest—but her imports are about the same as the local production. In Table 15 is given the available statistics in salt exports from manufacturing countries, the figures, such as they are, showing the United Kingdom to be far the greatest exporter, with Spain, Germany, and China next, the United States only exporting comparatively small quantities. If an export trade is to be developed in Australia, consideration must be given both to low cost of production and to quality.

In Table 16 are given the imports of salt by countries, which shows India to be the greatest importer, with British East India, Canada, and the United States also large importers. With regard to the two latter countries, the imports of the United States are gradually reducing, while those of Canada are generally on the increase, more particularly in values.

Australia before the war imported salt from England, but during the war became self-supporting. The salt produced in Victoria and South Australia is now of good quality and very little has to be done to make their productions equal to the very best English and American brands. Table 17 gives particulars of the imports of the various States of the Commonwealth and Table 18 the countries from which salt supplies have been received.

These tables also show the value per ton of the imports, and also give some information in other ways. Table 18 shows that the value of the imported rock salt varies from less than £1 per ton to over £2 per ton, these values, however, probably being f.o.b. at port of shipment and exclusive of c.i.f. charges.

N.E.I. quantities and values are mostly those of salt in bags, and an abnormal value to the quantities shown in the table is probably due to "salt preparations" put up in packets heavier than 14 lb. Some of the highest values in imports are those delivered to South Australia, but they are small special consignments and have no bearing on the general average.

Table 18 shows that the principal country exporting salt to Australia is the United Kingdom, but the trade which has been carried on throughout the war is gradually diminishing although the value of the imports is increasing. United States during the war, and Germany before the war, have supplied Australia with

salt preparations and bagged salt, but not with rock salt. The values as a whole vary from 15s. to £5 10s. per ton, the lower values being rock salt before the war, the high values that of refined salt in bags during the war, *c.i.f.e.* charges of course being excluded.

Countries not included in the production tables include Abyssinia, Argentine, Brazil, China, Ecuador, German East Africa, Hawaii, Korea, Northern Nigeria, Persia, Philippine Islands, Portuguese East Africa, Portuguese India, Roumania, Somali, Switzerland, Turkey, and Venezuela. All these countries are salt producers and appear to produce over 20,000 tons annually, but the statistics are too fragmentary to tabulate. In China the brine wells at Tze-lin-ching in Sye-chuan, which are worked in a very primitive manner, are estimated to yield 175,000 tons per annum, but no figures are available. The yields of Turkey are also very large and in late years the production amounts to over 300,000 tons annually, with a selling value of about £3 per ton.

India and other parts of Eastern Asia, except Japan, appear to be open markets for salt, and the northern parts of Queensland are particularly well situated for the establishment of works having in view an export trade to those countries. The article, however, must be equal to English and American qualities, and it would be useless sending the crude salt there, of which they are able to produce large quantities themselves. The Indian salt values are less than 8s. per ton for local crude salt but £4 per ton for the high qualities which are imported.

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TABLE 17.—ANNUAL IMPORTS OF SALT BY AUSTRALIAN STATES.

States Importing.			Year.				
			1913.	1914-15.	1915-16.	1916-17.	1917-18.
<b>ROCK SALT—</b>							
New South Wales	..	Tons	7,719·80	7,754·75	6,193	3,052	850
Value	..	£	6,132	5,903	4,880	3,492	1,676
Value per ton	..	£	0 15 10½	0 15 2½	0 15 9	1 2 10½	1 19 5
Victoria	..	Tons	771·50	1,109·10	676·25	..	..
Value	..	£	825	1,037	668	..	..
Value per ton	..	£	1 1 4½	0 18 8¼	0 19 9	..	..
Queensland	..	Tons	630	482·95	665	..	..
Value	..	£	830	607	962	..	..
Value per ton	..	£	1 6 4	1 5 1½	1 8 11¼	..	..
South Australia	..	Tons	119	84·55	63	10	39·15
Value	..	£	105	116	86	15	162
Value per ton	..	£	0 17 7½	1 7 3½	1 7 3½	1 15 0	4 3 0¼
Western Australia	..	Tons	47	157·20	57	23	171·15
Value	..	£	46	178	53	47	551
Value per ton	..	£	0 19 6¾	1 2 8	0 18 7	2 0 10½	3 4 5
<b>SALT PREPARATIONS IN PACKAGES NOT EXCEEDING 14 LB.—</b>							
New South Wales	..	Value £	5,974	4,575	4,080	6,002	13,534
Victoria	..	Value £	2,206	1,428	2,579	2,254	1,557
Queensland	..	Value £	1,074	1,299	2,326	1,157	1,056
South Australia	..	Value £	629	396	569	292	274
Western Australia	..	Value £	225	31	182	93	166
Tasmania	..	Value £	260	270	159	126	259
Northern Territory	..	Value £	..	428	6	..	..
<b>N.E.I. (mostly Salt in bags)—</b>							
New South Wales	..	Tons	8,164·40	4,466·10	2,568·55	469·35	1,261·65
Value	..	£	11,795	8,685	4,970	2,105	6,148
Value per ton	..	£	1 8 10½	1 18 10¾	1 18 8	4 9 9	4 17 6
Victoria	..	Tons	3,957·30	1,771·65	1,292·85	246·30	851·15
Value	..	£	6,299	2,968	2,418	1,635	1,588
Value per ton	..	£	1 11 10	1 13 6	1 17 4¾	6 12 11	1 17 4
Queensland	..	Tons	4,576·90	2,342·10	1,886·90	111·85	164·25
Value	..	£	7,861	4,545	3,458	497	866
Value per ton	..	£	1 14 4	1 18 9¾	1 18 7½	4 8 8¾	5 5 7
South Australia	..	Tons	368·15	151	110·30	10·75	·15
Value	..	£	695	288	221	27	2
Value per ton	..	£	1 17 9	1 18 1¾	2 0 2	2 9 1	13 6 8
Western Australian	..	Tons	217·70	66·55	10·80	5·55	1·15
Value	..	£	318	101	41	22	9
Value per ton	..	£	1 9 2	1 10 1	3 14 6	3 13 8¾	7 16 6
Tasmania	..	Tons	81	22	..	..	·60
Value	..	£	210	63	..	..	4
Value per ton	..	£	2 11 10	2 17 3	..	..	..
Northern Territory	..	Tons	..	200	..	..	..
Value	..	£	..	428	..	..	..
Value per ton	..	£	..	2 3 7	..	..	..

TABLE 18.—PRINCIPAL COUNTRIES' EXPORTS OF SALT TO AUSTRALIA.

			Year.				
			1913.	1914-15.	1915-16.	1916-17.	1917-18.
<b>ROCK SALT—</b>							
United Kingdom .. ..	Tons		9,220·30	9,262·60	7,627·60	3,085·10	1,034·20
Value .. ..	£		7,821	7,409	6,520	3,554	2,274
Value per ton .. ..	£		0 16 11½	0 15 11½	0 17 1	1 1 8½	2 3 11½
United States .. ..	Tons		..	..	26·75	..	26
Value .. ..	£		..	..	129	..	115
Value per ton .. ..	£		..	..	4 16 5	..	4 8 1
Germany .. ..	Tons		65	325·95	..	..	..
Value .. ..	£		113	432	..	..	..
Value per ton .. ..	£		1 14 8	1 6 6	..	..	..
<b>SALT PREPARATIONS IN PACKAGES NOT EXCEEDING 14 LB.—</b>							
United Kingdom .. ..	Value £		8,250	6,466	7,135	6,828	7,603
United States .. ..	Value £		2,075	1,528	2,576	3,051	9,183
Other British Countries ..	Value £		43	4	189	45	..
<b>NOT ELSEWHERE INCLUDED (mostly Salt in bags)—</b>							
United Kingdom .. ..	Tons		13,110·60	6,810·50	5,709·85	414·65	405·15
Value .. ..	£		20,148	11,637	10,658	1,976	1,940
Value per ton .. ..	£		1 10 8½	1 14 5½	1 17 4	4 15 2½	4 15 9½
United States .. ..	Tons		179·70	989·45	155	379·10	833·40
Value .. ..	£		595	3,265	434	2,107	3,782
Value per ton .. ..	£		3 6 1½	3 6 0½	2 16 0	5 11 2	4 10 9½
Germany .. ..	Tons		4,025·15	1,218·45	..	50	..
Value .. ..	£		6,342	2,166	..	200	..
Value per ton .. ..	£		1 11 6	1 15 6½	..	4 0 0	..

### Consumption of Salt in Australia.

The utmost difficulty has been experienced in obtaining information regarding the consumption of salt in Australia, and only an approximate estimate can be formed. This is based on the assumption that the amount of salt consumed or otherwise utilised is 55 lb. per capita per annum. In some countries it is considered that 45 or 46 lb. is a fair average, but taking into account the many channels for salt utilisation, such as in the preparation of foods, preservatives, medicines, and in various manufacturing industries, the above estimate does not appear to be excessive. In any case the estimate is more a matter of opinion rather than fact, because so many kinds of merchandise in the way of imports and exports have salt in their composition in which the contained quantities cannot be gauged.

In applying this estimate of 55 lb. to the population of each of the States it is found that the State consuming the most salt

is New South Wales, a non-producer of salt, while South Australia, by far the largest producer, is a small consumer. Queensland probably consumes more salt in the meat industries than the other States, but on the other hand utilises comparatively little in other salt-consuming industries compared to New South Wales and Victoria.

On the above basis has been compiled Table 19, which shows that Queensland consumes about 17,000 tons of salt per annum. Even on the basis of 45 lb. per capita the consumption would be about 14,000 tons, and this could be taken as the estimate of the minimum quantity consumed. For the whole of Australia the quantity estimated is 122,000 tons annually, which is, as shown in the table, the estimated quantities produced or imported.

TABLE 19.—ESTIMATED CONSUMPTION OF SALT IN AUSTRALIA (1915)  
(Based on the estimate of 55 lb. per capita per annum.)

State.	Estimated Con- sumption.	Estimated Production and Imports.		
	Tons.			Tons.
New South Wales ..	46,000	}		
Victoria .. ..	35,000		Salt Production .. ..	105,000
Queensland .. ..	17,000		Salt Imports .. ..	16,000
South Australia* ..	11,000		Salt imported in Commodities	1,000
Western Australia ..	8,000			
Tasmania .. ..	5,000			
Total ..	122,000	Total .. ..	122,000	

\* Including Northern Territory.

### Market Prices of Salt, and of Salt By-Products (Approx.).

The production and value of salt in a number of countries are given in Table 14, from which the market prices per ton can be roughly gauged, although it is impossible to state whether the values are those of the salt as it is produced at the works or the values plus charges such as taxes or dues, or f.o.b. prices at ports—that is, including all taxes and dues. The value variations arising from these factors are sometimes considerable, but from the table a general conception at least may be formed of salt prices throughout the world.

Queensland prices may be gauged somewhat accurately, as the quotations given below have been obtained from agents. Best

English duty free salt in bags, including c.i.f.e., before the war was about £4 10s. per ton, but the importation ceased during the war, and now the Commonwealth salt is used almost exclusively. The war gave a tremendous impetus to the manufacture of salt of high quality in Australia and the demand continues. English packet salt, put up in packets of less than 14 lb. in weight, has a small demand, however, and, including c.i.f.e. and an *ad valorem* duty of 15 per cent., is quoted at £8 10s. per ton. Rock salt is duty free if imported from the United Kingdom, but if from foreign countries £1 per ton is imposed, while a duty of £1 per ton is charged on "n.e.i." salt, such as that put up in packets or bags over 14 lb. in weight, whether from the United Kingdom or foreign countries.

The largest salt manufacturing companies in Australia have a common scale of prices for the various grades of salt, but evidently, so far as Queensland is concerned, there is no arrangement by which their individual spheres for doing business is limited.

In Table 20 are given the general prices of Australian salt in Queensland at the present time, modifications of which are to be made according to quantities and other conditions.\* The prices are about 20 per cent. above those before the war, with an apparently upward tendency at the present time.

TABLE 20.—QUEENSLAND SALT PRICES 1920.

		Per Ton. £ s. d.
Crude, dirty ..	Used for chemical manures, cattle and sheep licks, refrigeration, &c.	5 2 6
Coarse .. ..	Used for salting hides .. .. .	5 15 0
Coarse .. ..	Used for meat and bacon curing, bread making, &c.	6 9 6
Fine .. ..	Used for packing bacon, &c., required for hot climates	6 17 0
Fine .. ..	Used for domestic purposes, &c. .. .	7 2 0
Fine .. ..	Used in dairying (butter and cheese) .. .	8 7 0

In Table 21 a tabulation is given of numerous salt by-products, including sodium sulphate, magnesium sulphate, sodium carbonate, sal soda, soda ash, caustic soda, silicate of soda, magnesium chloride, calcium chloride, bleaching powder, hydrochloric acid, bromine and its compounds, and iodine. The prices are based on English and local quotations, and embrace pre-war prices, those prevailing during the war, and those since the war.

TABLE 21.—MARKET PRICES OF SALT BY-PRODUCTS. (APPROXIMATE.)

	Pre-War.		During War.		Post War.		Rate.
	Year.	Price.	Year.	Price.	Year.	Price.	
SODIUM SULPHATE—							
English	1913	4/-	1915—1918	3/- — 5/3	1919	4/-	cwt.
Local	1913	8/-	..	..	1919	20/-*	cwt.
MAGNESIUM CHLORIDE—							
English	1913	6/- — 6/6	1917	45/-	1919	56/-	cwt.
Local	..	..	..	..	1919	149/-	cwt.
CALCIUM CHLORIDE—							
English	1913	5/- — 5/6	1917	46/8	1919	12/-	cwt.
Local	1913	14/-	..	..	1919	20/- — 37/8	cwt.
BROMINE—							
English	1910—1913	2/4 — 2/6	1917	12/-	..	..	lb.
Local	..	..	..	..	1919	12/-	lb.
POTASSIUM BROMIDE—							
English	1910—1913	140/- — 172/8	1915—1918	£33—£130	1918—1919	£15—£61	cwt.
Local	1913	140/- — 168/-	..	..	1919	£20—£50	cwt.
SODIUM BROMIDE—							
English	1910—1913	£9 — £10	1915—1918	£14—£100	1918—1919	£13 10/-—£100	cwt.
Local	1913	112/- — 149/-	..	..	1919	£16—£24	cwt.
English	1910—1913	10/6 — 11/8	1915—1918	11/4 — 16/3	1918—1919	14/- — 18/-	lb.
Local	1913	13/-	..	..	1919	14/- — 16/1	lb.
SODIUM BICARBONATE—							
English	1913	5/-	1915—1918	5/- — 8/-	1918—1919	7/3 — 10/6	cwt.
Local	..	..	..	..	1919	21/2	cwt.

TABLE 21.—MARKET PRICES OF SALT BY-PRODUCTS. (APPROXIMATE)—continued.

	Pre-War.		During War.		Post War.		Rate.
	Year.	Price.	Year.	Price.	Year.	Price.	
SAL SODA (SODA CRYSTALS)—							
English .. ..	1913	5/6	1915—1918	2/2 — 7/-	1918—1919	4/4 — 5/3	cwt.
Local .. ..	..	..	..	..	1919	7/6	cwt.
SODA ASH (SODA CARBONATE)—							
English .. ..	1913	5/6	1917	21/-	1919	10/-	cwt.
Local .. ..	..	..	..	..	1919	19/7	cwt.
CAUSTIC SODA—							
English .. ..	1910—1913	15/- — 37/4	1915—1918	14/3 — 25/-	1918—1919	22/- — 34/-	cwt.
Local .. ..	1913	10/- — 18/-	1918	149/-	1919	38/-	cwt.
SILICATE OF SODA—							
English .. ..	1910—1913	130/- — 224/-	1917	261/-	..	..	cwt.†
Local .. ..	1913	10/-	..	..	1918	12/-	cwt.†
	..	..	..	..	1919	8/10	cwt.†
BLEACHING - POWDER (OXY-CHLORIDE OF LIME)—							
English .. ..	1913	7/-	*1915—1918	8/6 — 35/-	1918—1919	15/- — 35/6	cwt.
Local .. ..	..	..	..	..	1919	38/3	cwt.
HYDROCHLORIC ACID—							
English .. ..	1913	3/6	1917	37/4	..	..	cwt.
Local .. ..	..	..	..	..	1920	37/4	cwt.
MAGNESIUM SULPHATE (EPSOM SALTS)—							
English .. ..	1913	4/3	1917	32/-	1919	16/-	cwt.
Local .. ..	1913	8/6 — 9/-	..	..	1919	16/-*	cwt.

\* Australian.

† Crystals.

‡ Solution.

### Conclusion.

From the information furnished in the preceding pages it is evident that there are two very marked features concerning the prospects of making salt in Queensland, to wit, the favourable position of the Gulf of Carpentaria for making solar salt and the occurrence of brine beds in the sands and clays under Casuarina Island at the mouth of the Fitzroy River. There is also the possibility, later on, of utilising the salt in the Mulligan country or from the lakes much further east, and from the brine beds of the artesian strata in the Western districts which have been passed through in obtaining supplies of fresh water.

If solar salt works are established about the shores of the Gulf, it would be advisable to equip the works with a mechanical plant to finish by artificial evaporation the dense brines produced during the solar evaporation in the clay pans, and by this combination process the salt could be made at a low cost and would have the greatest possible purity. Such plants for artificial finishing are being established all over the world, and where they are installed and well managed, the industry progresses by leaps and bounds.

Freight to other ports might prove to be heavy and would impede progress to some extent, but with works established on a large scale this might be reduced very considerably if vessels could be employed specially for the work, or for the trade which would develop as a result of the establishment of the industry. The products would be absorbed by Queensland, and probably by New South Wales and the Northern Territory, while the proposed metallurgical works for leaching copper at Cloncurry might take very large quantities later on. Besides, the prospect of an important oversea trade developing in the countries to the north of Australia must not be lost sight of.

Casuarina conditions appear to be favourable for the installation of a complete plant to treat the brines direct by artificial evaporation, and its closeness to large centres of population would be a distinct advantage in reducing freight charges. In addition, the natural features of Casuarina Island indicate that the construction of extensive salt pans would be both easy and cheap if it were found desirable to augment the brine supplies by sea water evaporation, or if, once the works were established, it was found desirable to use sea water exclusively.

Climatic conditions are not so favourable here as in the Gulf of Carpentaria, although it appears that the quantities of salt produced by the solar evaporation of the brine have been entirely

satisfactory to those who have been experimenting with the proposition. The mainland in the vicinity of Casuarina Island also calls for attention as some of the bores sunk in the neighbourhood, it is said, also show the presence of strong brines.

The manufacture of salt by-products on or near Casuarina Island is also a matter for consideration. These by-products include such heavy chemicals as caustic soda, salt cake, soda ash, and silicate of soda. With cheap fuel from one or other of the many sources in the Central district either to the west of Rockhampton about the Dawson or Mackenzie Rivers, or to the north at the Styx River, together with cheap water carriage for the output, and also in being a position central for the whole of Queensland, Casuarina as a site for salt works seems to offer many attractions. If operations were to be undertaken on a large scale, it would be advisable to first put down additional bores so that absolute data regarding supply, extent, and composition of the brine be obtained. It must also be remembered that the Fitzroy River is sometimes flooded, and provision would require to be made to prevent any damage to the works when the river is in flood and bringing down sediment.

Other coastal positions further north are favourable in some respects, but the heavy summer rains would be troublesome and, as stated previously, might necessitate covers or aprons being constructed for the protection of the brines in the ponds, and this means a considerable outlay of capital.

The Mulligan River salt areas are very far from the railway, and the only chance of their being developed lies in a railway connection being established with Winton, and it is very questionable whether the construction of a line would be advisable if only a salt traffic were to be depended upon.

Salt water beds in artesian strata have been recognised in many localities where bores have been sunk, and while in some cases the flows and positions have been recorded, no attention has been given to their composition and density. It is known that some of the artesian beds about the Georgina River and Sandringham in the Boulia district contain saturated brines which are apparently in a perfect condition to be operated upon for their salt contents, and no doubt there are other natural brine occurrences of which no notice has been taken.

Information should be collected about the salt water met with in all artesian bores, and samples of the water should be tested for composition, more particularly from those bores on the eastern side of the artesian basin which are not far from railway

communication. No doubt large supplies would be obtained from the bores along the western border, specially to the south-west of Boulia, which might be worked in conjunction with some of the large deposits of lake salt occurring there, but the isolated position of this part of the State would be a very serious handicap in any salt undertaking, that is, unless the salt could be obtained here more cheaply than at Burketown to supply Cloncurry, if any developments warranted the use of salt there in any leaching process for treating the copper ores.

### Addendum.

During the inquiries regarding the salt consumption in the States of the Commonwealth another of the numerous instances was discovered regarding the defective system of recording information in the Commonwealth Statistical Returns. We wanted to know the amount of salt consumed in Queensland, but the only items given under salt were *oversea imports*, with nothing about interstate trade. Such statistics are quite useless as a guide to industrial mineral requirements within the States, and make impossible an estimate on the probable demand for any of our products should developments take place in the way of opening up deposits to mine the raw products or of establishing works to treat them.

To enable new industries being developed in Queensland it is part of the duty of the Geological Survey Office to estimate the extent of mineral deposits and determine their technical uses and values, and we put in the hands of the prospector or promoter all that is required in the way of data, except the one item on which depends the ultimate success of the whole concern—that is, the probable demand for the articles proposed to be placed on the market. The existing salt works of Australia are thousands of miles away from many of the ports of Queensland, notwithstanding which we are debarred from knowing what our consumption of salt is, because, forsooth, we are within the Commonwealth.

The effect is to retard prospecting developments in all classes of mining except in metals and coal, of which the market values are well known. Capital may be ready, Government advice and assistance is available, technical details are all satisfactory, but there is the hesitation to operate because of the one missing item—the assurance of local demand.

From another point of view it seems only right that such statistical returns should be published. Queensland is a country

of great mineral possibilities, and a knowledge of the requirements of other States would certainly have a tendency to create interstate trade and to eliminate oversea imports. Besides, coming more closely to Queensland's individual interests, we should be in a position to cater for our own needs, especially in the salt required for the dairying industry, instead of depending on supplies from other States, particularly when we could produce the article we import cheaper than the States which supply us.

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# ASBESTOS.

REPRINT.

## Article 2 in **INDUSTRIAL MINERALS**

*By B. DUNSTAN, Chief Government Geologist.*

(Publication No. 268, in Part)

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*Queensland Geological Survey, Department of Mines, Brisbane.*

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A Review of Occurrences, Treatment, Uses, Values and Production,  
with Special reference to Queensland Resources.



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## Article 2.—ASBESTOS.

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## Article 2.—ASBESTOS.

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### Queensland Localities.

The Cawarral-Canooka Serpentine Belt is a large area of country to the north-east and north of Rockhampton, extending from Balnagowan near the Fitzroy River to Marlborough in the direction of Broomsound. This area contains asbestos deposits in a number of localities and records have been made of their occurrence at Broadmount, Tungamull, Mount Wheeler, Mount Etna, Morinish, Princhester, Mount Fairview at Canooka, Clifton Station near Marlborough, and Dalcalmah near Glen Geddes Railway Station. Asbestos is also found in serpentine in the Kilkivan district at Mount Muir and Black Snake, in the Kandanga district near the Blue Bell Copper Mine near Wodonga Creek to the south-south-west of Gympie, at Yarrol on the Burnett River, at Calliope near Gladstone, and at Eddystone to the north of Mitchell in the Maranoa District. At Mount Pring, close to Bowen, a serpentine area has been recently prospected showing the presence of asbestos in small quantities, and a deposit between Petford and Fossilbrook on one of the branches of the Tate River has lately been opened up.

The deposits at Princhester and Marlborough appear to be those of most importance, although as a matter of fact very little is known of the value or extent of any of them. About nine miles to the north-north-east of Princhester, which is only an old township site, the asbestos has been found in mountainous country north of Paddock Creek, a branch of Tilpal Creek, about four miles from the railway now under construction between Rockhampton and St. Lawrence. Some years ago mining operations in this locality revealed numerous veins of soft asbestos along a face 20 ft. wide, but the thick overburden evidently discouraged the prospectors, and the work was abandoned. From a personal interview with one who worked in the mine, and from the fact that £25 per ton was offered for the product, it would appear that the deposit is of an encouraging character and that it should have further work expended upon it.

Twelve or thirteen miles south-south-east of Marlborough asbestos veins occur in the area bounded by Devlin and Marlborough Creeks and the Fitzroy River, those on Marlborough Creek near its junction with the Fitzroy River containing veins said to be numerous, silky, clearly defined and with the fibre  $1\frac{1}{2}$  inches long. A few miles from Princhester Railway Station

other deposits exist, and the serpentine country to the north of this township is known to contain veins of asbestos of varying quality. At Dalcalmah near Glen Geddes Railway Station, near Marlborough, a deposit of some importance has been revealed, and as the asbestos is in demand for numerous purposes the discovery is worthy of attention. Asbestos deposits also occur about two miles from the Ayr-Bowen tramline and about twelve miles by road from Bowen, the mineral being exposed on one of the steep spurs on the south-western side of Mount Pring.

### Other Localities.

In New South Wales deposits of asbestos have been worked at Gundagai, but trials made of the product have not resulted in their development. During the last two years asbestos has been worked at Barraba in New England, and the results of trials have been so satisfactory that developments in a large way are contemplated. At Woodsreef in the same district another deposit has been opened. Asbestos has been found in many localities in South Australia but does not seem to have been successfully mined, although discoveries of Crocidolite in limestone have been made at Robertstown, and of Chrysotile asbestos at Minbrie near Cowell, tests of which were considered very satisfactory.

Tasmania produced inferior asbestos many years ago but the industry made no progress. Recently, however, the Anderson's Creek deposits near Beaconsfield have been reopened and the product is now being utilized in the manufacture of cement-asbestos slates and sheets.

Reports from Western Australia have drawn attention to asbestos at Soanesville on the Pilbarra Goldfield where two lodes have been exposed, the fibre being short but of fine quality.

In South Africa asbestos veins were worked a few years ago at West Griqualand, and in Rhodesia deposits opened up some time ago were abandoned. Recently operations started again at the latter locality and future prospects are now considered to be very promising. The occurrence of the mineral has been recorded in the Transvaal and deposits have been worked to some extent in Cape Colony, Natal, Nyasaland, Cyprus, India, Japan, China, Siberia, and New Zealand. Italy was once the most important asbestos-bearing country in the world, but Canada now occupies the premier position, with Russia and Rhodesia next in importance.

### Mineral and Geological Notes.

Numerous asbestiform varieties of minerals are known to

science, and of these Hornblende asbestos and Chrysotile asbestos are the two kinds mostly in demand for industrial purposes, a third kind—called Crocidolite or Blue Amianthus—being utilised to a limited extent, while a fourth variety—called Pyroxene asbestos—has been recorded. Types of the three principal kinds are the Italian asbestos (Hornblende in part); Canadian, Russian, and Rhodesian (Chrysotile); and West Griqualand or “Cape” blue asbestos (Crocidolite).

Table 22 gives the composition of the above four varieties of asbestos, which shows a uniformity in the percentages of the substances in both the Chrysotile and Hornblende varieties, even though the latter is not associated with serpentine. The Crocidolite variety from West Griqualand is low in magnesia and high in iron, while the Arkoba asbestos in South Australia is higher in magnesia and lower in iron, and is a form having some of the qualities of the hornblende variety. The Broughton “lime asbestos” (Canada) and the Gundagai variety (N.S.W.) are both low in magnesia and water and high in lime, features which indicate their uselessness as fibre. Other minerals occur in a fibrous form but none are of any technical value.

TABLE 22.—COMPOSITION OF ASBESTOS.

Locality	Water.	Silica.	Magnesia.	Alumina.	Iron Oxides.	Soda.	Other Constituents.
<i>Chrysotile Variety.</i>	%	%	%	%	%	%	%
Black Lake, Quebec, Canada	14.48	39.36	42.15	..	3.51	..	
Broughton, Quebec, Canada..	13.55	40.87	41.50	0.90	2.81	..	
New Haven, New Jersey ..	14.25	42.62	42.67	0.38	0.27	..	
Minbrie, nr. Cowell, S.A. ..	11.20	36.58	35.03	1.68	1.20	0.44	Lime, 6.84; CO <sub>2</sub> , 5.94
Reichenstein, Germany ..	13.80	43.50	40.00	0.40	2.08	..	
Pilbarra, West Australia ..	14.82	42.98	39.92	0.44	1.92	..	
Pilbarra, West Australia ..	14.01	42.20	40.73	1.60	2.08	..	
Anderson's Creek, Tasmania..	8.46	42.80	41.86	2.24	5.04	..	
Takara, New Zealand ..	13.90	41.12	42.52	0.68	1.54	0.16	Potash, 0.16
<i>Hornblende Variety.</i>							
“Italian” .. .. .	14.02	40.25	40.18	2.82	0.75	1.37	Potash, 0.15
<i>Crocidolite Variety.</i>							
West Griqualand, S. Africa ..	4.50	51.22	2.48	..	34.08	7.07	
Arkoba Station, S. Australia..	3.71	51.33	12.18	3.93	21.76	5.91	Lime, 1.32
<i>Pyroxene Variety.</i>							
Broughton, Quebec, Canada..	4.17	44.85	11.85	2.36	16.25	..	Lime, 19.05
Gundagai, New South Wales*	2.10	57.38	21.34	0.13	5.60	..	Lime, 13.22
Dalcalmah, Glen Geddes, Central Queensland	4.00	56.70	19.30	2.60	5.80	..	Lime, 11.2; MnO, 0.4

\* The analysis suggests a “Lime” Asbestos, but its associated rock is serpentine.

Serpentine, with two exceptions, is the matrix or close associate of all known asbestos deposits of value. It is a hydrous silicate of magnesia, greasy or soapy to the touch, generally has innumerable polished joints or faces, is of a light or dark-greenish colour, sometimes mottled red or yellow, and is easily scratched with a knife blade. The rock is supposed to have been peridotite or olivine, which afterwards became hydrated, the formation of the asbestos being a subsequent effect. Recent investigations show that the asbestos is a direct recrystallisation of the serpentine, and that the veins will not form unless the original rock, peridotite, is first changed to serpentine.

Canadian asbestos generally occurs in veins formed in irregular or parallel joints in the serpentine, the veins varying in thickness from  $\frac{1}{4}$  in. to 3 in., but averaging less than 1 in., a dozen or more such veins forming a group probably in a width of several feet, with another similar group not far away. Such a group of veins, and others like it with barren serpentine or peridotite between, might extend intermittently, and often very irregularly, for hundreds of feet, the belt in which they all occur perhaps being continuous for several miles.

Russian asbestos, so far as the Urals are concerned, is in an area of serpentine which has been disturbed by intrusions of diabase and porphyry, the asbestos being confined to lenses of rock sometimes over 3,000 feet long and 1,000 feet wide. The mineral occurs in horizontal and vertical veins, cross-fibre being the common variety present, although other forms exist.

The Anderson Creek deposits in Tasmania are in serpentine flanked by what appears to be a sedimentary rock, while those at Pilbarra in Western Australia are in serpentine which is said to be an altered peridotite. This rock intrudes an adjacent sedimentary formation and is itself intruded by several dolerite dykes. The deposits about Rockhampton are in serpentine in the vicinity of basic intrusions, similar conditions prevailing in several other localities in Queensland where the serpentines contain asbestos.

At Barraba in New South Wales the asbestos is in the form of veins about one inch thick and occurs in a belt of serpentine, the veins being numerous and fairly close to one another. Up to the present time this deposit appears to be the most successful one opened up in New South Wales and produces a fibre superior to anything yet found in Queensland.

The Minbrie asbestos deposit in South Australia is in association with serpentine, marble, &c., the rocks containing about half per cent. of crude hand-picked fibre with about 15 or 20 per cent. of milling rock.

Asbestos nearly always crystallises with the length of the fibre at right angles to the walls of the veins, but sometimes it occurs parallel with the walls, and occasionally without any definite arrangement at all. The first form is vein or cross fibre; that along the walls is slip or parallel fibre, the third form being massed fibre, all having the same physical properties, and generally of equal value.

Italian asbestos has a staple sometimes 2 ft. long, and usually takes the form of pockets or patches in serpentine, while the Russian and Australian deposits are much like the Canadian in their mode of occurrence, that is, as veins in serpentine. The West Griqualand deposits are in jaspers and ironstones in quartzose schist, and are not associated with serpentine.

Rocks commonly found with the asbestos-bearing serpentine include granite, granulite, porphyry, diorite, dolerite, diabase, gabbro, hornblende and mica schist, quartzite, slate, shale, and crystalline limestone. The granulite, porphyry, diorite, dolerite, diabase, gabbro, and granite form intrusive dykes, the last-named also occurring as large irregular masses. The dykes are often closely connected with the asbestos deposits, and in some cases are said to be the cause of the formation of the veins.

Talc is closely related to serpentine both in composition and occurrence, and is commonly found in asbestos areas. It is more or less foliated, greasy, shining, semi-transparent, and easily scratched with the thumb nail. Steatite, or soapstone, an altered serpentine found frequently with asbestos, is white or grey, fine-grained, soft as talc, greasy, dull, never foliated, and similar to talc in composition. Picrolite is a rough, coarse, asbestiform serpentine, occurring as irregular patches in asbestos, and of very little value. Tremolite and actinolite are inflexible and coarsely fibrous or acicular forms of hornblende, felted varieties of the same mineral being Mountain cork, Mountain wood, and Mountain leather. Dolomite, magnesite, chromite, and magnetite occur as irregular masses, lenses, and veins in the serpentine, and sometimes in the asbestos, corundum also being found rarely in the serpentine as small irregular grains. Gold in serpentine and in asbestos is occasionally met with, and a gold-bearing quartz reef in serpentine is known to occur parallel with a vein of asbestos.

### Mining Notes.

Asbestos mining operations are confined to open cuts and quarries, no underground workings so far being undertaken in the areas where the deposits occur. Labour-saving appliances are generally necessary in economically working the mines, particularly if the veins of asbestos are small or few and contain low values. The asbestos deposits in some localities are worked entirely by manual labour, and the fibre is made ready for the market without further treatment, although only 5 per cent. of the total products are found to be sufficiently clean to do without machine-dressing in some way.

Quarries in the serpentine vary much in dimensions, and one 300 ft. long, 100 ft. wide, and 50 ft. deep would be considered of medium size. Some of the excavations are much larger, perhaps over 1,000 ft. long, others again being very much smaller with a working face perhaps five, ten, or twenty feet wide.

Asbestos veins averaging less than 1 in. in width may constitute a payable proposition if there are a number of veins to operate upon, and not too far apart, but with the veins a few inches wide the prospects would be considered very favourable. The fibre in the wide veins rarely extends unbroken from wall to wall, and frequently a number of minute partings of iron oxide or serpentinous bands parallel with the walls divide it into sections of varying lengths. Fibre 1 in. or more in length is of high value, although shorter lengths may become the main product (and the principal source of profit) if mining and milling operations are conducted on a large scale.

The average proportion of fibre in productive serpentine has been estimated to range from  $3\frac{1}{2}$  to  $7\frac{1}{2}$  per cent., and Table 23 has been prepared to show the commercial grades of the products, together with their percentages in the rock as taken from the mine and in that treated at the mill.

### Milling Notes.

The asbestos-bearing rock after being mined is broken up on tables by spalling and napping hammers, and the long fibre removed and graded by hand and sieves, the operation being known as cobbing. After this the broken rock is, in most cases, sent to the mill to have extracted the greater portion of the remaining fibre. In the mill the fibre is generally separated into

three lengths, respectively averaging  $\frac{5}{8}$ ,  $\frac{3}{8}$ , and  $\frac{1}{4}$  in., an additional product sometimes being an asbestic powder and sand made up of those portions of the mill waste which contain a high percentage of very short fibre mixed with serpentine.

A mill equipment usually consists of rock-breakers, rotary dryers, rolls, fiberisers, cyclones, rotary screens, suction fans, and grinding pans. The rock-breakers are either of the jaw or gyratory type, and crush the coarse material as it comes into the mill from the picking table, the reduced rock then passing to the rotary or other dryer to have all moisture removed preparatory to screening and further reduction. The fiberisers and cyclones contain beaters shaped like propellers, which break up the small pieces of rock and release the short fibre, but they have a tendency to cut up the fibre while pulverising the rock, and in some mills finishing rolls are used instead. The grinding pans (or ball mills) are necessary only when asbestic is to be one of the products.

The installation of milling plants on asbestos mines is generally found to be necessary after prospecting operations are completed, but in new areas it is advisable to first know the commercial value of the fibre, and this can be ascertained by forwarding samples to the Geological Survey Office, Brisbane. The next matter for consideration is the quantity of material available and its situation for cheap mining, treatment, and carriage to railway or port.

In Cyprus the asbestos is broken up by hand and separated from the gangue in dust chambers and flues, but the process is very primitive and only to be adopted where manual labour is very cheap.

Referring to Table 23, "Asbestos Mine and Mill Products," the grades given are based on the results from a well-furnished mill. Occasionally, as previously stated, the two grades from the mine are the only products saved, all the shorter fibre in the serpentine being considered as waste. At other mines, however, the hand-picking is dispensed with, and the mill treatment depended upon exclusively.

The average range of percentages in the grades shown in the table must be understood to be only an approximate estimate, and to be subject to much variation, although the information supplied will be found useful in connection with any propositions on the lines of Canadian mining and milling practice.

TABLE 23.—ASBESTOS MINE AND MILL PRODUCTS.

UNMANUFACTURED GRADES AND THEIR APPROXIMATE PERCENTAGES IN  
MINE AND MILL ROCK.

Products and Waste.	General Ranges of Percentages.	
From the rock mined—	%	
Crude asbestos—		
Grade 1 (over 1 inch)* .. .. .	0	to 0.3
Grade 2 (average $\frac{3}{4}$ inch)* .. .. .	0.3	„ 0.9
Milling rock .. .. .	30	„ 60
Mine waste .. .. .	40	„ 70
From the rock milled—		
Mill stock .. .. .	6.0	„ 12.0
Mill fibre No. 1 (average $\frac{5}{8}$ inch)* .. .. .	0.5	„ 2.0
Mill fibre No. 2 (average $\frac{3}{8}$ inch)* .. .. .	1.5	„ 4.5
Paper stock (average $\frac{1}{4}$ inch)† .. .. .	4.0	„ 8.0
Mill waste (or) .. .. .	88	„ 94
Asbestic powder and sand‡ .. .. .	44	„ 60
(and) mill waste .. .. .	34	„ 44
Contents of total asbestos—		
Crude asbestos (grade 1 and 2) .. .. .	3.0	„ 8.0
Mill stock—		
Mill fibres Nos. 1 and 2 .. .. .	20	„ 40
Paper stock .. .. .	60	„ 80
Total mine and mill product from rock—		
Total asbestos (all grades except asbestic) .. .. .	3.6	„ 7.4
Crude asbestos (grades 1 and 2)* .. .. .	0.3	„ 0.9
Mill stock (fibres 1 and 2)* .. .. .	1.5	„ 2.9
Paper stock (mill fibre No. 3)† .. .. .	1.8	„ 3.6
Asbestic (powder and sand)‡ .. .. .	20	„ 30
Total waste rock (mine and mill) .. .. .	67	„ 97

\* Spinning quality varies from  $\frac{3}{8}$  inch to over 1 inch.

† Quality suitable for the manufacture of paper, sheet, board, or other felted varieties.

‡ Suitable for paint, plaster, &amp;c.

As an illustration of the variations from these percentages which might be expected in actual operations, the table shows the maximum quantity of all fibre in the rock to be 7.4 per cent., which is a fair general estimate, although an average yield of 40 per cent. has been established at one mine, and even a 60 per cent. yield is recorded.

### Properties and Uses.

One of the main features to be considered in estimating the economic value of asbestos is its fire-resisting quality, the Italian, Canadian, Russian, and Rhodesian kinds all being good in this respect. The Cape (West Griqualand) asbestos is useless as a fire-resistant, although valuable as a heat insulator for moderate temperatures. Another important consideration is whether the fibre can be spun and woven, the hornblende, chrysotile, and crocidolite asbestos all being well adapted for this purpose.

The Italian chrysotile more effectively resists acid corrosion than the other kinds, and is therefore in demand for the purposes to which asbestos is applied in chemical works and laboratories.

Asbestos of high quality must be fine in the staple with at least 16,000 fibres to the lineal inch. It should be very flexible and strong, of a silky lustre, without colour, infusible at temperatures below 2,000 deg. F., and capable of being spun into a fine thread. Coarse rough asbestos is always very brittle, has no tensile strength, will not twist, and is quite valueless as fibre.

The valuable fibre varieties contain from 12 to 14 per cent. of water of crystallisation, an absence of which makes the fibre harsh and brittle. Where veins of asbestos have been exposed to the weather or have become altered in mineral composition by contact with intrusive dykes, the fibre is usually of little value, and the amount of water present is generally found to be less than 5 per cent. If the fibre is artificially heated to a high temperature most of the water of crystallisation is driven off, the fibre losing its silkiness and flexibility although retaining its fire-resisting property. A low percentage of magnesia and a high percentage of iron, as in crocidolite, causes the fibre to fuse if highly heated, a defect which makes it unsuitable for many purposes.

Grades with fibre  $\frac{3}{8}$  in. or more in length are utilised in making asbestos cloth, packing, rope, yarn, &c., grades of shorter length being made into sheet and board, and also utilised in asbestos building material. In making the better class of goods it is understood that at least 25 per cent. of the asbestos must have a fibre not less than one inch long.

Asbestos has its greatest use in fibro-cement, as boiler and pipe coverings and as steam packings, the demand for the cloth, board or sheet being comparatively small. Rubber is used with the asbestos in some forms of packing, particularly as a film covering for loose fibre, as a bond between asbestos layers, and as a core to asbestos rope. In coverings to prevent heat radiation from steam pipes the asbestos is sometimes mixed with vegetable fibre, such as cotton, while for packings and other purposes steatite is loaded into asbestos-rubber fabric, or filled into asbestos piping as a core, or worked into the fibre when being woven. Inferior asbestos mixed with tripolite makes a good boiler covering, both being good non-conductors of heat, while each acts as a bond to the other.

Mixed with portland cement the asbestos fibre is applied to the manufacture of roofing slates, flooring tiles, weather boards, lining boards, fire-proof coverings for both metal and wood, fire-resisting cement, &c., for most of which there is an ever-increasing demand. Some of these products require the addition of other ingredients such as fine sawdust, calcined magnesite, rubber, bitumen, and burnt clay. In the asbestos roofing slates a small proportion of asbestos is mixed with portland cement, and this when set with water under great pressure becomes hard and dense. The operations consist in making a mixture of the ingredients with water and then rolling the "dough" into sheets of the desired thickness. The sheets are stacked in tiers of 50 and subjected to a pressure of several hundred tons to remove air bubbles and excessive moisture. Afterwards they are cut into shapes of various sizes with stamping machines and placed in a steaming chamber for about 40 days, this operation producing a micro-crystalline structure in the bonding ingredients and making the material to a great extent impervious to water.

In the making of sheets from Barraba asbestos it is found desirable to use with it some of the crocidolite asbestos from South Africa.

Up to the present all the experiments tried with Queensland asbestos (and a great number have already been tested) show that the sheets and slates are actually weakened by its introduction and better material will require to be discovered before it can be said that asbestos from this State is suitable for making sheets and slates. At the same time the presence of the asbestos prevents cracking and enables the sheets to be worked much like wood. Tasmanian asbestos is found to answer fairly well, 25 per cent. of which is mixed with Canadian asbestos in the manufacture of slates and sheeting.

The use of asbestos in ordinary moulded cement roofing tiles is of no advantage whatever, and some experiments conducted with varying mixtures of cement and asbestos show unmistakably that a moulded cement tile has at least four times the tensile strength of one moulded of cement mixed with asbestos, so that the introduction of the asbestos actually weakens the tile. Another series of experiments indicated that a moulded cement tile took up about 13 per cent. of water on being submerged in water, while one with 5 per cent. of added asbestos absorbed under the same conditions twice this amount of water, and with 15 per cent. of asbestos the water absorbed was 48 per cent., nearly half the weight of the tile when dry. No doubt, the

strength of the tiles would be improved if they were made under pressure, and steamed afterwards, but this introduces features which bring them under the system of manufacture of sheets and slates which are so much lighter and more convenient to use.

In asbestos-cement lining boards the same ingredients are used, but with generally a larger quantity of asbestos, and the setting is not under such great pressure as with the slates. The product is tough, fireproof, and capable of being worked like wood. Experimental mixtures of portland cement and asbestos show that with 5 per cent. of asbestos a sheet will break when a nail is driven through it, but that 10 per cent. asbestos board will stand very well. Asbestos board of about 1 inch in thickness is used as a substitute for marble in electric switchboards, and is made up of asbestos fibre and asbestic powder with a small percentage of some binding ingredient.

As a floor covering asbestos and magnesia are being used effectively as a mixture, with magnesia chlorides as the binding ingredient. Queensland asbestos and magnesite is well adapted for this purpose, and properly prepared makes a very durable surface. Noticeable defects consist in the material not being acid-proof when laid down, a result due to using the magnesia incompletely burned, or after being burned allowed to remain exposed to the air to become recarbonated.

Corrugated portland cement-asbestos compositions are now used as a substitute for corrugated iron, while for the external ornamentation of buildings an asbestos stucco has been introduced.

Ground asbestos from Queensland localities is being used as a refrigerating paint and appears to give entire satisfaction.

Fire-resisting cements consist of about 60 per cent. of No. 2 mill fibre with admixtures of asbestic, portland cement, sand, &c. A cement used as a packing for the joints in the water-jackets of furnaces consists of three parts of asbestos, one of portland cement, and half of silicate of soda. An asbestos fire-brick coating is said to prevent clinkering and to eliminate the bad effects of abrasions, and sometimes the whole of the lining of a furnace is made up with asbestos as part of the composition.

### Production and Values.

The Canadian production of asbestos for 1917 shows some interesting figures. The quantity of asbestos rock mined was 2,018,078 tons which yielded 120,984 tons of mill asbestos, representing a recovery of 6 per cent. and an average of 6,448 tons mined per day. The total quantity of asbestos sold during the year was 120,984 tons, having a value of £1,496,479 and an average per ton of £12 7s. 4d. The sales of asbestic amounted to 16,320 tons, valued at £9,850 and equal to 12s. 1d. per ton.

TABLE 24.—TOTAL PRODUCTION OF ASBESTOS BY COUNTRIES  
(Compiled from Various Sources).

Country.	Year.	Quantity.	Value.	Value per ton.
		Tons.	£	£ s. d.
United States .. ..	1880-1917	40,805	373,590	9 3 0
Canada—				
*Asbestos .. ..	1879-1918	1,457,275	13,205,516	9 1 3
*Asbestic .. ..	1896-1918	357,000	101,485	0 5 8
	1891-1916	188,498	2,062,473	10 18 10
Russia .. ..				
†South Africa—				
Cape Colony, &c.—				
Asbestos .. ..	1890-1916	18,987	‡318,877	16 16 0
Crocidolite .. ..	1887-1912	206	17,485	84 17 6
Rhodesia** .. ..	1908-1918	26,631	491,969	18 19 6
India .. ..	1894-1917	157	348	2 4 4
Cyprus .. ..	1906-1912	2,643	17,710	6 14 0
Tasmania .. ..	1899-1918	3,514	5,830	1 13 2
Western Australia ..	1908-1909	43	1,754	40 15 10
Italy* .. ..	1893-1916	6,310	119,494	18 18 9
Portuguese East Africa*	1908-1917	6,753	446,026	65 0 3

\* Exported.

‡ Value partly estimated.

† Cape Colony produces most of the Asbestos mined.

\*\* Year 1918 partly estimated.

Russian high-grade asbestos in the past was sent to European countries, but the low grades apparently could not bear the prevailing high freight charges, and were not exported. The

demand is becoming greater, however, and until quite recently deposits were being vigorously exploited in an area in the Urals, said to be very large and practically inexhaustible.

TABLE 25.—ANNUAL PRODUCTION OF ASBESTOS BY COUNTRIES, 1914-1918.†

Country.	YEARS.				
	1914.	1915.	1916.	1917.	1918.
United States .. .. Tons	1,113	1,546	1,320	1,503	..
Value .. .. £	3,951	16,032	93,377	105,428	..
Canada (Asbestos) .. Tons	86,199	99,234	121,443	120,984	127,120
Value .. .. £	602,555	740,243	1,069,444	1,496,479	1,879,146
Canada (Asbestic) .. Tons	18,778	22,902	16,513	16,320	14,803
Value .. .. £	3,604	4,546	5,656	9,850	7,093
Russia .. .. Tons	17,103	8,551	8,062	..	..
*Value .. .. £	224,000	112,000	104,800	..	..
South Africa, Cape Colony Tons	1,167	2,138	4,582	..	..
Value .. .. £	19,550	*35,000	*75,603	..	..
South Africa, Rhodesia .. Tons	489	2,016	6,157	9,562	*7,000
Value .. .. £	8,612	32,190	100,431	192,520	*140,000
Tasmania .. .. Tons	..	..	15	271	2,854
Value .. .. £	..	..	30	271	5,008
Italy .. .. Tons	509	148	255	..	..
Value .. .. £	11,200	3,000	5,610	..	..
Total Quantities .. Tons	125,358	136,535	158,347	148,640	151,777
Total Values .. .. £	873,472	943,011	1,454,951	1,804,548	2,031,247

\* Estimated.

† Figures compiled from "Mineral Industry," "Mineral Resources of United States," "Mineral Production of Canada," "Mines and Quarries," "Engineering and Mining Journal," &c.

Canada as stated previously is the leading asbestos-producing country, her output being 77·5 per cent. of the whole asbestos production of the world. Russia yields 12 per cent. of the world's output, the United States and Portuguese East Africa each a little over 2 per cent., the remainder being furnished principally by South Africa, Italy, Rhodesia, and Cyprus, with small quantities from Tasmania and Western Australia, and still smaller amounts from India, Nyasaland, and Portugal. In value per ton the South African production is very much higher than that of Canada, and while the Cyprus production is nearly half that of Italy the value is less than one-sixth. Details of these productions are given in Table 24.

During recent years (see Table 25) Canada's production has been fairly constant although the greatest annual yield, so far as value is concerned, has been recorded in 1918. The average value of all grades was about £13 5s. per ton for that year, previous years' values varying from £6 10s. to £8. The United States asbestos production varies considerably from year to year, while the Russian annual output for a number of years until the war disarranged trade, was uniform in value and quantity, 99 per cent. of the yield coming from the Ural Mountains.

Many of the Russian companies are reported to have formed a monopoly in 1916 to handle the asbestos, and the annual production is said to reach 18,000 tons, although the statistics available do not bear this out.

The South African industry is increasing somewhat in importance, of that there is no doubt, and the deposits are said to be very valuable and to be the largest in the world. The Italian mines continue to produce small quantities of asbestos although statistics are not available, while the Cyprus mines produce nothing, not on account of the exhaustion of the deposit but simply because the owner is an ex-enemy subject and the product intended for Austrian requirements.

Table 26, showing exports of manufactured asbestos for the five years ending 1916, reveals the whole world's trade in asbestos both in values and quantities, showing all countries which have produced the material and those to whom it has been exported. Some inconsistencies exist regarding the returns of Canadian exports to the United Kingdom and the United States, so the two sets of figures available are both included.

The average value per ton of asbestos exported by countries, irrespective of grades, is given in Table 27. The Canadian production is shown to be the lowest in every year between 1912 and 1916, the average of the whole of the years being £7 11s. 9d. per ton. While this value is low some consideration has to be given to the fact that the industry is a very important one, and both high and poor qualities of material is exported to all parts of the world.

TABLE 26.—EXPORTS OF UNMANUFACTURED ASBESTOS BY COUNTRIES.\*

Country Exporting.	YEAR OF EXPORTATION.				Country. Importing.
	1913.	1914.	1915.	1916.	
†Canada .. .. Tons	7,538	10,113	17,493	12,247	United Kingdom
†Value .. .. £	74,988	93,426	212,564	187,079	ditto
‡Canada .. .. Tons	6,446	9,997	19,580	12,829	ditto
‡Value .. .. £	44,138	79,684	155,000	128,214	ditto
‡Canada .. .. Tons	69,783	52,055	50,586	65,355	United States
‡Value .. .. £	441,732	324,029	358,780	589,592	ditto
Canada .. .. Tons	77,288	64,089	83,540	102,659	ditto
Value .. .. £	395,385	290,361	412,656	639,503	ditto
Canada .. .. Tons	750	2,454	..	..	Germany
Value .. .. £	7,602	19,784	..	..	ditto
Canada .. .. Tons	15,709	7,886	5,355	8,222	Other Countries
Value .. .. £	99,871	55,387	55,947	88,956	ditto
Canada—Total .. Tons	92,780	72,508	73,434	86,406	
Value .. .. £	624,193	496,626	627,291	806,762	
United States .. Tons	1,106	1,607	3,305	3,523	United Kingdom
Value .. .. £	5,750	16,813	36,396	37,768	ditto
Russia .. .. Tons	1,580	1,253	205	2,570	ditto
Value .. .. £	45,617	29,181	4,045	73,876	ditto
Cape Colony .. Tons	567	832	2,713	3,293	ditto
Value .. .. £	8,572	19,137	78,213	99,040	ditto
Germany .. .. Tons	350	264	..	..	ditto
Value .. .. £	8,508	9,200	..	..	ditto
Portuguese East Africa .. Tons	193	294	710	2,704	ditto
Value .. .. £	4,119	5,926	15,398	78,288	ditto
††Italy .. .. Tons	96	75	35	35	ditto
Value .. .. £	2,636	4,402	1,603	1,202	ditto
Other Countries .. Tons	173	205	742	2,339	ditto
Value .. .. £	2,774	3,524	8,148	65,705	ditto
¶Other Countries .. Tons	4,674	2,667	5,295	5,342	Italy
§§Value .. .. £	56,000	32,000	63,000	64,000	ditto
Other Countries .. Tons	17,297	..	..	..	Austria-Hungary
§§Value .. .. £	207,564	..	..	..	ditto
Total Quantities .. Tons	104,242	79,705	86,439	106,212	
Total Values .. .. £	965,901	616,813	834,630	1,228,641	

\* Compiled from "Mineral Production of Canada," "Mineral Resources of the United States," and "Mineral Industry."

§ See text notes on values of exports to the United States.

† Mineral Production of Canada (quoted from "British Trade Report").

‡ Mineral Production of Canada (Official Table).

|| Canada, Germany, and Russia.

§§ Values estimated at a general average of £12 per ton.

|| Mineral Resources of United States and Mineral Industry.

†† Probably includes some "manufactured" asbestos.

TABLE 27.—AVERAGE EXPORT VALUES PER TON OF ASBESTOS, 1913-1916.  
(Based on Table 26.)

Country.	1913.	1914.	1915.	1916.	General Average.
	£ s. d.	£ s. d.	£ s. d.	£ s. d.	£ s. d.
Canada .. .. .	6 13 0	6 16 0	8 11 0	9 6 9	7 11 9
United States .. .. .	5 4 0	10 9 6	11 0 0	10 14 6	8 13 0
Russia .. .. .	28 17 6	23 6 0	19 14 6	29 10 6	26 0 0
South Africa .. .. .	15 2 6	23 0 0	28 16 6	30 1 6	22 12 3
Germany .. .. .	24 6 0	34 17 0	..	..	29 17 6
Portuguese East Africa .. .. .	21 7 0	20 3 0	21 14 0	28 19 0	20 10 6
*Italy .. .. .	29 6 0	58 14 0	45 16 0	34 7 0	41 3 9

\* Probably include values of some manufactured asbestos, as unofficial records show prices to be about half those given in the Table.

In Table 28 are given the names of the countries which import asbestos, the quantities consumed by each being indicative partly of internal trade and partly of a re-export trade. The two greatest consumers of asbestos in the world, as shown from the table, are the United States and the United Kingdom, while Germany's imports by comparison appear to be very small. It will also be observed that Germany has only received very small quantities of asbestos from Canada, and has no mines of her own, but German companies before the war owned all the principal Russian mines, and probably most of the Russian yields of unmanufactured fibre have gone to Germany.

Most of the Canadian mill stock grades in the past have been sent to the United States in an unmanufactured condition, the higher grades being exported to Belgium, England, France, and Germany. Large quantities of asbestic—as fire-proof paint and plaster for building decoration—are being utilised in Canada, the United States also using it to a limited extent.

Several of the exporting countries shown in Table 26 have contributed to the imports of the United Kingdom, Germany, United States, &c., but the quantities are very small. The imports if required, however, can be obtained from this table, although it will have to be assumed, with some risk it must be stated, that the statistics of the exporting country are the same as those of the country which imports the material.

TABLE 28.—IMPORTS OF UNMANUFACTURED ASBESTOS BY COUNTRIES, 1913-1917.

Country Importing.	YEARS.					Country Exporting.
	1913.	1914.	1915.	1916.	1917.	
*United Kingdom.. Tons	7,538	10,113	17,493	12,246	..	Canada
Value .. .. £	74,988	93,426	212,564	187,080	..	..
*United Kingdom.. Tons	1,580	1,253	205	2,570	..	Russia
Value .. .. £	46,617	29,181	4,045	75,876	..	..
*United Kingdom.. Tons	567	832	2,713	3,293	..	Cape Colony
Value .. .. £	8,572	19,137	78,213	99,040	..	..
*United Kingdom.. Tons	1,106	1,607	3,305	3,523	..	United States
Value .. .. £	5,750	16,813	36,396	37,778	..	..
*United Kingdom.. Tons	193	294	710	2,704	..	Portuguese
Value .. .. £	4,119	5,926	15,398	78,288	..	East Africa
*United Kingdom.. Tons	613	544	777	2,374	..	Other Countries
Value .. .. £	13,918	17,126	9,751	100,244	..	..
Total .. Tons	11,597	14,643	25,203	26,710	..	
Total Value .. £	154,064	181,609	356,367	580,306	..	
†United States .. Tons	77,289	64,090	83,540	102,650	117,433	Canada
Value .. .. £	395,336	290,360	412,656	639,503	864,212	..
†United States .. Tons	..	..	..	100	1,599	British South
Value .. .. £	..	..	..	2,214	35,002	Africa
*Germany .. Tons	750	2,454	..	..	..	..
Value .. .. £	7,602	19,784	..	..	..	..
†Italy .. Tons	4,674	2,667	5,295	5,342	..	..
Value .. .. £	..	..	..	..	..	..
†Austria-Hungary Tons	17,297	..	..	..	..	..
Value .. .. £	..	..	..	..	..	..
Other Countries .. Tons	154	76	1	1,409	264	..
Value .. .. £	6,156	2,921	153	75,485	13,677	..

\* From "Mineral Production of Canada."

† From "Mineral Resources of the United States" and "Mineral Industry."

The value of the imports of asbestos by the United Kingdom, United States, and Germany for the years 1912-1917 are given in Table 29 together with the general average value per ton for each country during this five-year period. The highest import values are credited to the United Kingdom and the lowest to the United States, but Germany's import values for recent years are not available. When dealing with imports of mixed manufactured and unmanufactured material the values rise very much higher than those shown in Table 29, and in analysing the statistics given in the various official publications it is sometimes found impossible to tell which kind is meant.

Cape asbestos imports to the United Kingdom are not available, but in June 1917 some of this asbestos was sent to England, and it is said to have realised £25 per ton.

TABLE 29.—AVERAGE IMPORT VALUES PER TON OF ASBESTOS, 1913-1917.  
(Based on Table 28.)

Country.	1913.	1914.	1915.	1916.	1917.	General Averages.
	£ s. d.	£ s. d.	£ s. d.	£ s. d.	£ s. d.	£ s. d.
United Kingdom ..	13 5 6	12 8 0	14 2 9	21 14 6	..	15 9 3
United States ..	5 2 3	4 10 6	4 18 9	6 4 6	7 7 0	5 9 6
Germany .. ..	10 3 0	8 1 6	..	13 5 0	..	10 2 0

The value of the Commonwealth imports of asbestos during the year ending June 1918 amounted to £32,407, the millboard, yarn, and cloth imports being valued at £3,808 and pipe coverings, boiler coverings, and packings at £28,599. Direct oversea imports into Queensland amounted in value to £2,816, but no records are kept of supplies from other States. Besides the above there are imports of large quantities of roofing slates and other kinds of building material made up of asbestos and the ingredients referred to previously, which would not come under the above classification.

### Quotations and Prices.

Table 30, showing Canadian and New York prices of unmanufactured asbestos in 1915, must be taken very approximately, as the numerous standards which have been adopted cannot be closely correlated, some grades being based on the length of the staple, others on the value of the product. From the data supplied, however, an estimate can be formed of the comparative value of all the primary asbestos products even though the actual value may not be correct. Early in 1917 Canadian asbestos reached high prices and Crude No. 1 realized from £200 to £240 per ton, Crude No. 2 varying from £120 to £160 per ton. Later on in 1917 prices receded, and the average returns for the year showed "Crude" to be £106 per ton, "Mill stock" £7 per ton, and "Asbestic" 10s. 9d. per ton.

TABLE 30.—PRICES OF UNMANUFACTURED ASBESTOS PER TON.

Grade.	Canadian.	New York.	Grade.	Canadian.	New York.
	£	£		£ s.	£ s.
Crude No. 1 ..	60	77	Paper stock ..	3 0	4 10
Crude No. 2 ..	34	49	Asbestic powder	0 6	..
Mill fibre No. 1 ..	12	26	Asbestic sand ..	0 3	..
Mill fibre No. 2 ..	9	20			

Asbestos prices within the Commonwealth during 1915 showed a great increase on those of Canada and the United States. Crude fibre of grades 1 and 2 varied from £200 to £400 per ton, and retailed at 2s. 6d. to 5s. per lb., since which quotations have not been obtainable. Asbestos rubber packing in the form of loose fibre, containing from 20 to 25 per cent. of rubber, and considered to be very efficient as a packing for glands, &c., before the war was quoted at £700 and £900 per ton, or 8s. and 10s. per lb. retail, recent prices being from 12s. 6d. to 15s. per lb. High-priced asbestos goods, it may be mentioned, are generally those in which rubber is part of the composition.

Before the war, rope lagging for steam pipes containing about 25 per cent. of cotton was quoted at about 10s. to 20s. per 100 ft. according to thickness, 1916 quotations being from 12s. 6d. to 22s. 6d. Prices in 1918 varied between 20s. and 50s. and recent (1920) between 20s. and 80s. Asbestos rope, cord, twine, and cloth, consisting entirely of the grades known as crude Nos. 1 and 2 and mill fibre Nos. 1 and 2 in 1916 were quoted at 2s. 6d. per lb., 1918 prices being from 4s. to 5s. per lb. and 1920 prices 5s. 6d. to 6s. Asbestos cloth is sometimes made up of about 20 per cent. rubber and reinforced with strands of very fine brass wire, the wholesale price of this article in 1916 being 3s. per lb., and between 4s. 6d. and 5s. per lb. retail in 1918, and 5s. 6d. in 1920.

Millboard, sheet, and other felted forms of manufactured asbestos are made up of what is called paper stock, the shortest mill fibre mixed with small quantities of asbestic, prices of which in 1916 ranged from £30 to £60 per ton, retailing at 4d. to 8d. per lb. In 1918 prices ranged from 8d. to 1s. per lb. with a single quote in 1920 of 1s. per lb. Prices of thick sheets suitable for electrical switchboards are about 1s. 6d. per lb. Asbestos cements for firebrick furnace linings, or lutings for retorts, were in 1916 quoted at prices ranging from £15 to £40 per ton, or about 2d. to 5d. per lb. In 1918 the prices were from £40 to £45 per ton, no quotations being obtainable later.

Asbestos-portland cement roofing slates contain about 20 per cent. of asbestos, and before the war were quoted at £20 per 1,000 (about £14 per ton). Prices in 1916 were £28 per 1,000 (about £20 per ton), recent prices being about £26 per 1,000 (about £19 per ton). Asbestos-cement sheets, containing from 12 to 20 per cent. of mill fibre No. 2 and used for inside linings, before the war were quoted at £13 per ton, in 1916 were quoted at £16 per ton, and are now at £29 per ton, equal to 3s. 3d.

to 3s. 6d. per square yard according to thickness, which varies from 4 to 5 mm. ( $\frac{5}{32}$  to  $\frac{3}{16}$  inch).

To complete the data regarding costs of material required in the asbestos industry, it may be stated that the price of rubber is from £336 to £448 per ton, or from 3s. to 4s. per lb., portland cement being about £4 per ton before the war and £5 17s. 2d. per ton at the present time. The other ingredients mentioned are of minor importance, either from their low value or because of the small quantities used. Regarding import duties most of the asbestos goods are liable to a duty of 20 per cent., *ad valorem*, those with rubber in their composition having a duty of 25 per cent., while a few lines such as asbestos millboard and sheet come in duty free. Rubber is subjected to a general tariff of 15 per cent. and a preferential tariff of 10 per cent. The duty on portland cement is 30s. per ton, general, and 20s. per ton, preferential. Asbestos-portland cement sheets and slates (fibro-cement, &c.) are liable to a general tariff of 30 per cent. and preferential tariff of 25 per cent.

### Conclusion.

The brief notes on asbestos localities might be taken as a basis for further investigations if circumstances warrant the consideration of any proposition to establish an asbestos industry in Queensland, while the information supplied on the mining and milling of the raw material might be useful should this be followed by practical development. The grading of the asbestos and the technical application of the products, together with the notes furnished on production and prices, will enable an opinion being formed or an estimate being made on questions bearing on (1) the manufacture of asbestos goods, (2) the trade which might develop as a result of the establishment of the industry, (3) the possibility of foreign competition, and (4) the commercial aspect as revealed from an inquiry into the costs of the raw material and the prices obtained for the manufactured articles. No details are given concerning the differences between manufacturers' costs and selling prices, but the figures supplied will be sufficient on which to form an approximate estimate should that be desired.

Regarding the possibilities of foreign competition and the commercial aspect, it may be stated that before establishing an asbestos industry within the Commonwealth consideration would have to be given to the asbestos resources of Canada and the export trade which has developed in that country, and it would also be well to bear in mind the large unworked deposits

of Russia, and those now being vigorously developed in South Africa. With only local markets to cater for, however, the competition from these countries could easily be overcome if a good deposit of asbestos were to be discovered, but to establish an oversea trade, even if the quality of the mineral were found to be as good as that of the Canadian mines, there would be several serious commercial difficulties in the way.

The Queensland asbestos deposits so far developed have not yielded good material, but there are many uses to which the product, such as it is, could be applied, particularly in the manufacture of boiler coverings, refrigerating paint, and asbestos-magnesite floorings, and for such other applications where heat insulation, non-decay of the binding fibre, and proof against acid corrosion are important factors.

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**MICA.**

**REPRINT.**

## Article 3 in **INDUSTRIAL MINERALS**

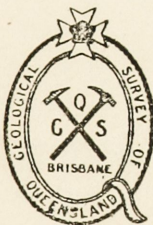
*By B. DUNSTAN, Chief Government Geologist.*

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*Queensland Geological Survey, Department of Mines, Brisbane.*

A review of Occurrences, Treatment, Uses, Values and Production,  
with Special Reference to Queensland Resources.



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## Article 3.—MICA.

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## Article 3.—MICA.

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### Queensland Occurrences.

Pegmatite veins containing large crystals of mica are known to occur on many of the mining fields of Northern Queensland, the deposits on the Einasleigh River to the south-east of Georgetown and at Brookland near Junction Creek, both within the Etheridge Goldfield, being specially worthy of note. Attention has been directed to the occurrence of deposits of mica in the Cloncurry district, and from recent examinations they appear to be of more importance than anything previously known in the State. They are situated on Rifle Creek, a tributary of the Upper (West) Leichhardt River, on Parkside No. 6 Pastoral Lease, and about 68 miles almost due west of the town of Cloncurry. Many references are given in the Queensland Mineral Index to mica occurrences, but without any information regarding their extent or value.

### Other Localities.

In the Northern Territory a mica mine was opened and abandoned some years ago at Hart's Range, to the north of Arltunga Goldfield, and in 1914 operations were again started, the war, however, stopping the work at the mine in consequence of the mica being intended for Germany. In South Australia it is reported to occur in an area near Williamstown, in the hundred of Barossa, and a low-grade deposit has been opened near the Warren Reservoir in the hundred of Para Wirra.

India has yielded by far the largest quantity of mica in the world, but Canada is now an important producer. The United States has also yielded large quantities of mica, while England and German East Africa have produced the mineral in a small way.

Many other parts of the world produce mica of good quality, notably Nyasaland, South Africa, Ceylon, Argentine, Brazil, West China, Transvaal, Madagascar, and Norway, but so far the deposits are small and the quantities produced negligible.

### Geological Features.

The country about the Rifle Creek mica area is said to be in hornblendic and micaceous schist, in which a dyke of pegmatite

was discovered to be made up almost exclusively of large crystals of mica, the thickness of the dyke being from 10 to 12 ft. A large number of pegmatite dykes, some with quartz predominating, occur in the locality, but have not been examined, although the mica-bearing belt is said to extend for several miles.

Samples for examination have been received from the outcrops of these deposits, but no attempt seems to have been made to determine the character and quality of the mica below the surface. The mica is very much stained with iron oxides, and generally is in a very defective condition, as might be expected, but no doubt any blemishes in this surface material would disappear if the mica were obtained in deeper ground. Some of the crystals have well-developed cleavages, are roughly 9 in. square, and after being stripped and trimmed, even in their weathered condition, have given very satisfactory tests, electrical and otherwise.

The Central Australian deposits near Arltunga are in mica schist in the form of large pegmatite dykes of felspar, quartz, and mica. Some of the mica crystals obtained were several feet in diameter, and one specimen is said to have yielded 7 cwt. of trimmed mica sheets.

In India the mica occurs in gneiss and schist country traversed by pegmatite dykes or lenses, intrusive dykes also being present. Some of the dykes are of no value on account of the presence of too much quartz, while in other dykes containing large quantities of mica the crystals are too small. The veins are up to 20 in. in width, and the best mica is where the veins are in contact with the mica schists. Colourless or "white" muscovite is the mica commonly mined, but pale shades of ruby, green, and brown muscovite also occur of value, the ruby tinted mica being considered the best in quality.

The Canadian mica is phlogopite or "amber" mica, of a yellowish brown colour, the mica occurring with apatite and calcite in irregular masses and dykes of green pyroxenite. In Korea (Chosen) this variety of mica is associated with altered calcareous sedimentary rocks close to granite-gneiss. Phlogopite is usually associated with altered limestones and with serpentinous rocks.

The United States deposits of mica are in gneiss and schist made up of mica, hornblende, garnet, and quartz. Deposits also occur in other metamorphic rocks, the matrix being dykes,

lenses, or irregular masses of pegmatite, the mica occurring as large books of muscovite with or without quartz, and sometimes without felspar.

In German East Africa the mica of commercial value is a muscovite having light green and brown shades. It occurs in pegmatite dykes varying from 30 to 70 ft. thick, the surrounding country being biotite gneiss.

### Mica Varieties.

Numerous varieties and sub-varieties of mica are known, those most common being Lepidolite, Lepidomelane, Biotite, Phlogopite, and Muscovite. Lepidolite is a lithia mica, containing from 4 to 5 per cent. of lithia, and valuable on this account. It is usually of a pale-rose colour and fine-grained, but occurs in violet and yellow tints. Biotite is the common magnesia-iron mica, between Phlogopite and Lepidomelane in composition. It is usually black, but is sometimes dark green, brown, and red, and, as it contains much iron, is of but little value. Phlogopite, the magnesia mica, occurs in various shades of brown, yellow, red, and green, but is sometimes colourless and occasionally mottled. It is a useful mica, and often valuable. Lepidomelane is the iron mica, always black, very seldom in large sheets, and quite useless. Muscovite is the potash mica, and is usually colourless or "white," although sometimes having brown, green, yellow, ruby, or violet shades. It is quite as soft as Phlogopite, but as it is less resilient it is not considered to be as useful or as valuable as this magnesian variety.

TABLE 31.—COMPOSITION OF PRINCIPAL MICA VARIETIES.

—	SiO <sub>2</sub>	Al <sub>2</sub> O <sub>3</sub>	Fe <sub>2</sub> O <sub>3</sub>	MgO	K <sub>2</sub> O.	Na <sub>2</sub> O.	H <sub>2</sub> O.	Other Constituents.
	%	%	%	%	%	%	%	
Muscovite—								
Bengal .. ..	45.57	36.72	2.23†	0.38	8.81	0.62	5.05	
Tyrol .. ..	45.28	37.59	1.18*	0.17	10.32	1.20	4.12	
Rifle Creek ..	44.00	33.60	5.00	1.50	10.20	..	4.70	MnO <sub>2</sub> —0.5%
Lepidolite—								
Norway .. ..	49.52	28.80	0.40	..	12.63	0.13	1.72	Li <sub>2</sub> O—3.87%
Paris .. ..	50.92	24.99	0.30	..	11.38	2.11	1.96	Li <sub>2</sub> O—4.20%
Biotite—								
Vesuvius .. ..	39.30	16.95	8.45*	21.89	7.79	0.49	4.02	
Freiberg .. ..	34.70	17.17	19.55*	9.52	8.91	1.24	3.56	
Phlogopite—								
Korea .. ..	..	..	2.05	25.45	8.98	1.09	..	F 0.75%
Ceylon .. ..	42.26	15.64	1.75†	27.23	8.68	..	2.91	F 2.19%
Ontario .. ..	39.66	17.00	0.74†	26.49	9.97	0.60	2.99	F 2.24%
Lepidomelane—								
Freiberg .. ..	37.50	17.87	30.80†	10.15	0.83	3.00	3.48	
Baltimore ..	35.78	16.39	25.57†	8.67	7.76	0.56	4.48	

\* FeO

† Including FeO.

### Industrial Uses.

Desirable qualities in mica for industrial purposes consist of freedom from cracks, faults, or holes, the absence of magnetite, of quartz inclusions, and of impurities resulting from decomposition or surface infiltration. Sheets two feet in diameter are exceptionally large, sheets one foot in diameter being uncommon. Amongst its good qualities its property of splitting along the cleavages must be well developed, and the sheets should be flexible, resilient, transparent, and of a uniform softness. Regarding transparency a standard thickness of 2 mm. is used as a guide in determining whether the grade should be "wine coloured," "smoky," or "spotted." The cracks are sometimes irregular, but frequently are parallel with crystallographic faces and in groups of straight lines, while faults, even though in miniature, interfere seriously with the perfect splitting of the sheets. The absence of magnetite is very essential where the mica is used for electrical insulation, as by its presence the dielectric resistance is reduced—a very undesirable quality. Brittleness is generally a bad feature, while fine quartz grains make the sheet useless for certain parts in electrical machinery in which uniformity in the texture of the mica is absolutely necessary. Other impurities, such as clay and oxide of iron, may be dielectric, but they usually attract hygroscopic moisture, and thus lower the electrical resistance. Softness is required in mica used for electrical appliances constantly in motion, and is a valuable quality, while otherwise soft mica is adapted to the making of magneto condenser plates and of appliances connected with wireless work.

The uses of mica, other than for electrical work—which absorbs the great bulk of the material marketed—are extremely varied and generally well known, but applications for powdered mica have been found in the manufacture of fireproof and paints, wall-papers, rubber manufacture, roofing compositions, and heavy machinery lubrication. Mica powders coloured with coal tar dyes also make good bronze pigments. If the powders are coarse a spangled effect is produced, if fine a uniform frosted or metallic colour is produced. The mica in this form is also used as a lustrous hair powder.

In the United States and Canada a large number of mills are operating on mica and are grinding it to powder for the purposes enumerated above. The machines used are disintegrators, in which the arms travel at many thousands of revolutions per minute, and the mica pieces are ground to powder instantaneously. From these machines the powder is taken by

pneumatic tubes into sizing bins where it is allowed to settle. Afterwards it is made up into packets of dry powder or mixed with oil or other vehicle. Another method consists in grinding the mica in water, then drying it with steam, and afterwards sizing the powder in silk screens.

### Prospecting, Mining, and Treatment.

In prospecting operations the mica may be expected to be found in gneiss or foliated granite, schists of various kinds, and in limestone where associated with metamorphic rocks. The limestone is not usually found accompanying mica deposits, but its occurrence has been recorded. The mica in the pegmatite veins frequently merges into an aplitic formation of quartz and felspar, and sometimes the vein or mass is made up exclusively of quartz. Mica will weather away to a clay without leaving any trace on the surface to indicate its presence below, but quartz, its usual associate, often forms conspicuous outcrops, from which the position of the mica deposits or the line of the pegmatite vein may often be traced.

It may be interesting to prospectors to know that very few mica deposits which have been proved valuable in other parts of the world have given any indication of their worth by their surface indications, while another fact to remember is that usually 10 per cent. of good mica in a vein would constitute a very payable proposition, this, of course, varying considerably with the position, accessibility, and conditions of labour.

In mica mining much care and judgment is required to obtain the crystals as large as possible, and one essential is the careful use of explosives in opening up the deposit, blasting powder being preferred. Dynamite and other high explosives are sometimes indispensable, but they are more destructive to the mica crystals than blasting powder. In cleaning the mica at the mine all quartz and felspar particles have to be removed, the felspar in some countries being saved as a by-product. The mica is then roughly trimmed and graded, and is sometimes sent away in this "unmanufactured" state. The crystals are now split into sheets about one-sixteenth of an inch in thickness and graded for quality and size. Further trimming and splitting, and the elimination of defective patches by wedges and long thin-bladed knives are the next operations, and from the material so treated all grades in quality and in rough-trimmed shapes and sizes are made.

The manufacture of definite shapes and the building up of "mica board" is another operation. The large shapes are cut

with knives or guillotines, the smaller ones, such as washers, being usually cut out by punching machines. The thin-splitting is a delicate operation, in which sheets are obtained of about one five-hundredth of an inch in thickness. To perform this operation the edges of thick sheets are ground smooth, but with a slight bevel, the smooth edge readily breaking up into thin leaves when pressed against a hard smooth surface. The splitting started on the edges is then completed with knives. Machinery for performing some of these operations has been introduced, the success of which, however, has not yet been demonstrated. The mica boards are built up from these thin sheets, which are then cemented together with shellac, pressed and dried, and afterwards ground to a uniform thickness.

In India the scrap mica accumulated for many years has not been utilised in any way, and large quantities are available for any use to which they might be put in future; but in other countries this waste mica is all pulverised, by either wet or dry methods, and is utilised in many ways after being graded in bolting machines to several degrees of fineness. Sheets of large size, or those which have special qualities, fetch high prices, and, although small sizes are also in demand if of good quality, deposits do not pay to work which will only produce small sheets. The question of what pays to work, however, is modified by such conditions as cost of labour, freights, and distance to market, and these may be too unfavourable to allow a deposit to be worked even when large crystals are obtainable. Some mining companies send the whole of the mica, after rough trimming, to a central co-operative factory, where the sheets are worked up and graded and made into articles ready for use, but other mining companies do this themselves, and export the whole of their product as "manufactured" mica.

### Production and Values.

The mica fields of India, Canada, and the United States practically make up the world's production, and up to the end of 1917, the total value of this, with a small amount from German East Africa and the United Kingdom, was about £6,631,212. The value of the Indian production was £3,822,197 (57.64 per cent. of the whole), that of the United States being £1,724,171 (26.00 per cent.), Canada, £899,426 (13.56 per cent.), and the United Kingdom £97,500 (1.47 per cent.).

The last recorded annual values are those of 1917, in which year the United States production reached a value of £157,780, that of Canada being £74,760,\* and India £508,173.

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\* Figures for 1918 show the Canadian production to be 667 tons, valued at £56,573.

The value per ton of sheet mica in the United States during the year 1917 was £271 17s. 6d., or about 2s. 5d. per lb. For Canada during the same period the value of the mica (unclassified) was £70 16s. 3d. per ton, or about 7½d. per lb., while in India the mica *exported* in 1917 was valued at £162 15s. 6d. per ton, or about 1s. 5d. per lb.

In 1917 the United States imported unmanufactured mica sheets both from Canada and India to the extent of 293 tons, having a total value of £86,420, the average value being £293 19s. per ton, or at the rate of about 2s. 7½d. per lb.

Great Britain imports of mica in 1916 amounted in value to £216,932, averaging £96 16s. 9d. per ton, or 10d. per lb. India supplied most of this importation, the value of which was £200,720, Canada also supplying mica to the value of £7,699.

TABLE 32.—TOTAL MICA PRODUCTION OF COUNTRIES.\*

Country.	Year.	PRODUCTION.		Value per Ton.
		Tons.	Value.	
			£	£ s. d.
United States—				
Sheet Mica .. ..	1880—1917	9,074	1,546,037	170 7 6
Scrap Mica .. ..	1893—1917	55,739	178,134	3 4 0
Canada .. ..	1886—1890	392	38,713	98 15 0
Canada .. ..	1891—1905	..	365,638	..
Canada .. ..	1906—1917	7,653	495,075	64 13 9
†India .. ..	1897—1917	35,159	3,822,197	108 4 0
‡United Kingdom .. ..	1897—1913	231,337	97,500	0 8 6
German East Africa .. ..	1906—1912	577	87,918	152 7 6
			6,631,212	

Table 32, showing the total mica production of countries, indicates India to be the premier mica-producing country of the world, with the United States second in importance. The whole of the Indian output is valued at £108 per ton, that of the United States being £170 per ton exclusive of scrap mica, while the Canadian production has been valued at £65 per ton.

Accurate statistics of the mica fields of Canada are not obtainable, many deposits being worked that are not officially known, in addition to which the value of the exports are considered too much underrated, for which allowance must be made.

\* Compiled from Mineral Industry, Mineral Resources of the United States, Mineral Production of Canada, Records of the Geological Survey of India, Mines and Quarries, &c.

† Exported mica.

‡ A scrap mica by-product in preparing China clay.

Table 33, containing the recent annual productions, shows that India in 1915 far exceeded the output of other countries, and that in 1916 this yield was nearly doubled both in value and quantity. In calculating the production of Canada during the past few years the estimated value of the home consumption is added to the known exports.

TABLE 33.—ANNUAL MICA PRODUCTION OF COUNTRIES, 1911-1917.\*

Country.	YEARS.					
	1912.	1913.	1914.	1915.	1916.	1917.
United States (Sheet) Tons	333	759	249	247	386	543
Value .. .. £	58,921	73,649	58,029	77,957	109,268	147,579
United States (Scrap) Tons	2,880	4,752	3,330	3,535	3,958	2,902
Value .. .. £	10,223	17,196	10,712	11,369	14,564	10,201
Canada .. .. Tons	518	986	531	372	1,079	1,041
Value .. .. £	29,995	40,480	22,721	19,146	53,175	74,760
India .. .. Tons	2,192	3,124	2,025	1,520	2,735	3,122
Value .. .. £	284,290	347,451	237,310	183,947	311,680	508,173
United Kingdom .. Tons	29,962	32,986	..	..	..	..
Value .. .. £	11,317	12,734	..	..	..	..

\* From various sources.

TABLE 34.—EXPORTS OF MICA FROM COUNTRIES (IN VALUES).

Country Importing.	1912.	1913.	1914.	1915.	1916.
INDIA (ESTIMATED).*					
	£	£	£	£	£
†United Kingdom .. ..	167,800	205,000	140,100	108,600	..
†United States .. ..	52,200	63,900	43,600	33,800	..
Germany .. ..	35,700	43,700	29,800	23,100	..
Other Countries .. ..	28,500	34,800	23,800	18,400	..
§Actual Totals .. ..	284,290	347,451	237,310	183,947	311,680
CANADA.					
	£	£	£	£	£
¶United States .. ..	61,947	42,116	26,295	42,012	61,712
†United Kingdom .. ..	7,491	6,932	7,910	7,096	17,065
Other Countries .. ..	156	1,114	3,073	83	330
Totals .. ..	69,594	50,162	37,278	49,191	79,107
UNITED STATES.					
	£	£	£	£	£
**Totals .. ..	11,614	15,908	15,425	9,198	17,336

\* Figures are partly based on the percentage export values shown in Table 81 in "Mineral Production of India," 1915. Page 183.

§ From "Mineral Production of India."

† Figures are inconsistent with those in Table 35, showing exports.

¶ From "Mineral Production of Canada," 1915.

\*\* Chiefly exported to Canada, England, France, and Germany (Min. Ind.).

TABLE 35.—IMPORTS OF MICA BY COUNTRIES (IN VALUES).

Country Exporting.	1912.	1913.	1914.	1915.	1916.
UNITED KINGDOM.*					
United States .. .. .	£ 1,257	£ 1,038	£ 2,582	£ 3,726	£ 2,323
†India .. .. .	136,224	145,859	95,915	93,398	200,720
†Canada .. .. .	8,916	9,081	7,717	6,145	7,699
Germany .. .. .	3,853	3,490	2,963	..	..
Other Countries .. .. .	8,622	4,963	7,653	10,314	6,190
Totals .. .. .	58,872	164,431	116,830	113,583	216,932
UNITED STATES.					
*Totals .. .. .	£ 157,413	£ 197,454	£ 136,696	£ 145,023	£ 235,534

\* Chiefly from India and Canada, but also from German South-West Africa, Mexico, Brazil, and Japan. (Min. Prod. of Canada).

† Compare values with those in Table 34.

In Table 34 an attempt has been made to approximately estimate the value of the exports of mica from India, basing the figures on the actual quantity known to be imported from India, and using the proportions for each country as given in the "Mineral Production of India," 1915. The results show that the United Kingdom is by far the greatest consumer of mica from India, while the United States takes most of the Canadian production. The value of the exports from Canada to the United States, however, about equals that of India to the same country, but the total value of the exports of India and Canada to the United Kingdom is more than the Indian and Canadian exports to the United States.

The values of the imports of mica by countries, shown in Table 35, are not consistent with the official export values in Table 34, but it is not possible to trace the source of this error. Some allowances must be made for differences between c.i.f. and f.o.b. prices, although this would only affect the import and export values to a small extent. In Table 34 the value of the United Kingdom imports of mica is shown to average less than the imports into the United States, but this cannot be verified by comparison as the details of the latter country's sources of mica are not obtainable.

The Commonwealth's imports of mica prior to July, 1918, are obscured by the statistics being mixed with those of several

other minerals, such as fireclay and moulding sand, but in the year 1918-1919 New South Wales imported 29 cwt. valued at £1,516, Victoria imported 11 cwt. valued at £663, and Western Australia imported a small quantity valued at £7, the total for the Commonwealth being 2 tons valued at £2,186.\*

### Market Prices of Mica.

The average of the prices quoted by Canadian, Indian, and American dealers for first class mica required in electrical machinery and in stove and lamp work is very difficult to estimate, but the following figures are given, very approximately, for the three best grades, the prices being at per lb.:—

#### MICA GRADES AND PRICES.

2" x 2",	2s.,	1s.,	3d.	2" x 7",	11s.,	7s.,	2s. 6d.
2" x 3",	4s.,	2s.,	6d.	4" x 6",	14s.,	8s.,	4s.
2" x 4",	6s.,	3s.,	1s.	3" x 9",	14s.,	8s.,	4s.
3" x 3",	9s.,	5s.,	1s. 6d.	6" x 8",	18s.,	10s.,	6s.
3" x 4",	10s.,	6s.,	2s.				

Special prices are asked for sizes over 6 inches by 8 inches and for sheets of extra good quality, some of the quotations per lb. being 30s. or more.

The general average Commonwealth quotations during 1916 for mica from India, Canada, and the United States are as follow:—Below 6 in. by 4 in., 9s. per lb.; 6 in. by 4 in., 10s. per lb.; 8 in. by 5 in., 11s. 6d. per lb.; 12 in. by 5 in., 16s. per lb. For Indian "Ruby" mica, which is of special quality, the prices for the same sizes are 18s., 22s., 25s., and 36s. to 40s.

In scrap mica the United States values for 1915 were £3 4s. 4d. per ton, or  $\frac{1}{3}$ d. per lb., but ground mica made from scrap imported into the same country realised £4 13s. per ton, or a little over  $\frac{1}{2}$ d. per lb. In India at the present time very little value is placed on the large quantities of scrap mica there accumulated. In Canada no general estimate has been made of the values in scrap and ground mica, but a special line of fine white ground mica specially adapted to wall-paper decoration has been quoted at £15 per ton. Within the Commonwealth scrap mica was quoted at 8s. 6d. per lb., but the material so designated consists of good sheet mica below the standard size of 6 in. by 4 in.

In 1917 and 1918 prices kept rising, and in 1919 they were

fairly uniform in being about four times higher than the quotations of 1916. Whether these prices are to continue is a matter on which no opinion can be expressed, although some are of the opinion that prices must fall when trade becomes normal.

### Conclusion.

The Indian deposits are considered to be very large, and with the cheap labour prevailing in that country immense quantities of good mica could be produced profitably for many years to come. The war, nevertheless, has affected the supplies from the Indian mines, and the industry is somewhat stagnant at the present time.

In the United States and Canada the war has had the effect of increasing local mica production, and in China many occurrences of mica of a commercial quality have been examined, and operators are now preparing for an export trade.

The question for consideration so far as Queensland is concerned is whether the Rifle Creek deposits contain mica equal in quality to that imported from America and India, and if so whether mining and dressing operations could be carried on cheaply enough to allow of competition with this imported material. Imperial demands for mica in connection with electrical and wireless work have stimulated the interest in these deposits and should induce miners to open up the outcrops, and obtain some estimation of the value of the very large mica sheets at a depth where they are not affected by weathering agencies.

The distance from Rifle Creek to Cloncurry is 68 miles by road, and from Cloncurry to Townsville by rail 481 miles, altogether making 549 miles over which the product would have to be carried.

In the mineral belt of country extending for many miles to the north-west and south-east of Cloncurry, and embracing the Rifle Creek deposits to the west, there is a large number of outcrops of granite and schist which all appear to be the result of the alteration of the associated sedimentary rocks. This area contains pegmatite dykes in the granites and schists which have never been prospected and the conditions are ideal for the occurrence of mica in qualities and sizes suitable for manufacturing purposes.

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# Article 4.—MOLYBDENITE.

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## Article 4.—MOLYBDENITE.

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### Queensland Localities.

The principal molybdenite deposits in Queensland are contained in the Chillagoe Mining Field, the most important occurrences being at Wolfram, Bamford, Khartoum near Almaden, and Sandy Tate River. Other noted deposits also occur at Kidston on the Etheridge Goldfield, Ollera Creek on the Star Mineral Field near Townsville, and at Stanthorpe near the New South Wales border. In addition, deposits are known to exist in the Tyrconnel mine at Wombah near Mount Perry, at the Magnet mine between Cloncurry and Mount Cuthbert, at Rosedale to the north-west of Bundaberg, and at Cardowan on the Connor's Range westerly from St. Lawrence. Recently molybdenite has been found at Mount Morgan in the gold-copper sulphide ores, and although in traces and of no commercial value is nevertheless an interesting occurrence.

Official records show that the mineral occurs in small quantities in gold and other ore-bearing deposits, and that it is of frequent occurrence in the quartz reefs of the Gympie and Croydon Goldfields.

### Other Localities.

Within the Commonwealth molybdenite is produced in large quantities in New South Wales, the principal areas being at Whipstick in the Pambula District, and at Deepwater and Kingsgate in the New England district, with less important occurrences in many other places. In Victoria, Tasmania, South Australia, Western Australia, and New Zealand deposits are also known, most of which are unimportant, although some have certainly favourable prospects.

In South Africa several deposits exist in Rhodesia, Natal, and the Transvaal, those in the first-mentioned locality being a recent discovery and now undergoing exploration. In North and South America molybdenite is found in numerous places, occurrences being recorded in New Foundland, Nova Scotia,

British Columbia, New Brunswick, Ontario, Quebec, Colorado, Arizona, California, West Indies, Mexico, Peru, and Chili, of which the Ontario and Quebec deposits appear to be the most promising.

In Europe the mineral is to be found in England, Scotland, Sweden, Norway, France, Saxony, Austria, Russia, and Sardinia; and of these the Norwegian deposits are by far the most important. Asian records show that the mineral is to be found in Ceylon, India, Federated Malay States, Japan, and Siberia, although up to the present the occurrences have proved to be of very little value.

### Geological Features.

The rocks associated with molybdenite deposits are usually, although not invariably, rich in quartz and poor in mica, and include various types of granite, aplite, pegmatite, syenite, granodiorite, quartz porphyry, and felsite. The deposits are generally close to where one of these rocks junctions with a basic series, the latter usually including a number of sedimentary or metamorphic rocks such as gneiss, schists, slates, shales, and limestones. More often than otherwise the deposits are in an igneous rock close to sedimentary rocks, occasionally being at the junction of the two, and more rarely in the sedimentary rocks close to the junction. Deposits are also known to be in limestone, coal measures, ironstone, and sandstone, and in basic volcanic rocks, although such occurrences are rare.

The types of deposits carrying molybdenite considerably vary in character, but the most common of all is the irregular quartz masses in granites and gneisses, other deposits being in quartz lodes more or less defined, and in long, inclined, and ill-defined bodies of quartz known as pipes. Less common deposits are pegmatite and aplite veins and pipes in granites, schists, slates, and quartzites; while impregnations of the mineral sometimes occur along the joint planes of granites. A pyroxene at the junction of pegmatite and limestone is known to be molybdenite-bearing, and the mineral has also been found in garnet; while in gold-bearing reefs traces of it are not of uncommon occurrence.

In Queensland nearly all these types of deposits are to be observed. The molybdenite occurs very frequently within a few hundred feet of where granite comes in contact with sediments, the deposits being mostly in the form of pipes or irregular masses of quartz in granite and greisen. Occasionally the pipes are very tortuous and at times closely associated with joint

planes in or near the granite, the pipes in some cases being followed down for hundreds of feet, generally with lessening values as the distance from the granite contact increases.

At Wolfram the molybdenite pipes, of which there are hundreds on this field, are all in a belt of greisenised granite graduating in depth to a biotite granite. At Bamford similar pipes occur but more closely associated with wolfram and bismuth. About Stanthorpe the molybdenite is in the form of splashes and nests in aplite dykes traversing granite, or in the granite itself; while at Ollera near Townsville it is associated with wolfram, bismuth, and small quantities of tin in quartz veins occurring at the intersection of joint planes in granite. At Mount Carbine, 17 miles N.N.W. of the Mount Molloy Railway Station and 34 miles N.N.W. of Bibbohra Railway Station on the Cairns-Chillagoe line, molybdenite occurs throughout the field in association with wolfram in well-defined pegmatite dykes close to intrusive granite. At Lappa the molybdenite deposits so far mined are free from other minerals, but other deposits exist in which bismuth, tin, and wolfram are associated with the molybdenite, the lodes being in a greisen close to granite and taking the form of tortuous pipes. The Kitchener deposits at Khartoum near Almaden are in the form of both pipes and reefs, the latter occurring in the joint planes of the granite, with fine-grained granite and felsite dykes in the vicinity.

About Chillagoe the molybdenite is in a chloritoid formation in slate and is generally free from quartz, which constitutes an unusual mode of occurrence for the mineral. In the Herberton District about Coolgarra it is found in a sericitic matrix and in quartz lodes on the joint planes of granite, and at Wombah in the Mount Perry District a valuable deposit of the mineral has been discovered in the form of a well-defined pipe of quartz in granite, without other metallic mineral associates but frequently with calcite, the rich portions of the pipe being near the periphery. At other places near Mount Perry fissure veins are the form of the deposit, the country rock being a crushed granitic material more or less calcareous and close to aplite dykes.

At Boomarrie near Cloncurry molybdenite is found in a limestone close to schist country, but without granite (?) in the vicinity. At the Magnet, which is close to Naraku Railway Station and about 35 miles N.N.W. of Cloncurry, the rocks are biotite schist and granite, the molybdenite being in an irregular quartz lode in the schist with copper pyrites as a mineral associate.

In New South Wales several kinds of deposits are also known. A typical quartz pipe occurs at Kingsgate in New England, another one at Whipstick near Pambula, and a third at Boro Creek near Deepwater, while many other similar occurrences have been recorded. Pegmatite pipes are to be observed at Wilson's Downfall on the MacPherson Range, Deepwater, &c.; granite pipes at Whipstick, Kingsgate, &c.; garnet pipes at Whipstick; segregations and pegmatite with aplite at Booroolong, Wilson's Downfall, and other places. Quartz veins in greisen occur at Deepwater and at Elsmore near Tingha in the New England District, at Oban and Moonbi in the New England District, on the Black Range near Bega, and at Wilson's Downfall. Quartz veins in coarse granite have been observed at Moonbi, Attunga, and on the Black Range near Bega, and narrow quartz veins occur close to the junction of granite and sedimentary rocks near Nambucca at Warrell Creek. In the Bathurst District there are contact deposits at Yetholme and Gemalla, and garnet with wollastonite in association with molybdenite in a contact zone close to limestone at Mount Tennyson and Tarrana (Andrews). Generally the molybdenite deposits are in areas where tin abounds, and in this respect are different from the Queensland deposits which commonly occur in wolfram and bismuth country and are only rarely associated with tin.

The molybdenite deposits of Canada are much the same in general characters as those of Queensland and New South Wales, and apparently the Norwegian deposits are similar, Japanese deposits being in a zone of contact between granite and, evidently, limestone.

#### Mineral Associations.

The gangue of molybdenite is almost always quartz, with which there is commonly associated felspar and mica, and with chlorite, talc, or mica occasionally present in the matrix. Other associated non-metallic minerals include tourmaline, biotite, beryl, topaz, monazite, garnet, and pyroxene. Common metallic minerals found with molybdenite include wolfram, native bismuth, bismuthine (sulphide), mispickel (arsenic), magnetite, copper pyrites, cassiterite (tin), iron pyrites, pyrrhotite, galena, zinc blende, and scheelite. Above water level many of these minerals undergo oxidation and in this surface zone are to be found molybdite (molybdate of iron), chillagite (molybdotungstate of lead?) oxides of manganese, tungsten and iron, copper oxides and carbonates, scorodite (arsenate of iron), lead carbonate and sulphate, bismuth oxide and carbonate, and zinc carbonate and sulphate.

Molybdenite is an easily oxidised mineral, and if exposed disappears from its gangue much more readily than most of the other minerals with which it is associated, so that the only evidence of its presence in a lode below the surface may be the presence of small tabular shaped cavities in the rocks on the outcrop. With the presence of other minerals surface indications are deceptive, however, but by itself the little cavities left in the gangue, more particularly if the gangue is quartz, are very good indicators.

Common associations of molybdenite and other metallic minerals in the same matrix are as follows:—Molybdenite and wolfram; molybdenite, wolfram, native bismuth and bismuthine; molybdenite, native bismuth and bismuthine; molybdenite and iron pyrites; molybdenite and mispickel; molybdenite and copper pyrites; and molybdenite and cassiterite. Other minerals of rarer occurrence with molybdenite, such as scheelite, galena, zinc blende, pyrrhotite and magnetite, sometime make up a series of four or five metallic minerals in the one gangue in association with a variety of non-metallic minerals which might include fluorspar, barytes, calcite, tourmaline, felspar, muscovite, biotite topaz or beryl.

#### Molybdenum-bearing Minerals.

*Molybdenite*.—Colour, bluish lead-grey; has a metallic lustre and greasy feel; usually in the form of scales and flakes, sometimes in flat hexagonal crystals, occasionally granular or massive; has a basal cleavage, splitting into thin, bright, flexible leaves. Hardness, 1 to 1.5; can be easily scratched with the thumb nail; marks paper with a bluish grey streak. Specific gravity, 4.4 to 4.8. Resembles graphite, which, however, is much lighter in specific gravity and has not the bluish metallic tinge of molybdenite. It also resembles joseite, a gold-bismuth telluride having all the physical properties of molybdenite, except that its colour is of a darker shade of grey and is without the bluish tinge. *Composition*: A sulphide of molybdenum, containing 59.95 per cent. of molybdenum.

*Jordesite*.—Colour, black; powdery. *Composition*: Sulphide of molybdenum; said to be distinct from molybdenite and to be amorphous.

*Molybdite*.—Colour, lemon yellow to straw yellow; lustre is glassy or silky; generally finely crystallised in radiating groups, sometimes earthy or massive and encrusting. Hardness, 1 to 2. Specific gravity, 4.5. Resembles turgite in colour and other physical characters. *Composition*: Hydrrous molybdate of

iron (39.6 per cent. of molybdenum), once thought to be molybdic oxide; results from the decomposition of molybdenite. Sometimes impure from the admixture of tungstic and bismuth oxides. *Occurrence*: In association with molybdenite, wolfram, and native bismuth at Bamford.

*Wulfenite*.—Colour, yellow, orange, red, brown, and olive green, also colourless; streak, white. Forms thin, square, tabular crystals; also massive; usually with a resinous or vitreous lustre, sometimes very brilliant. Hardness, 2.7 to 3. Specific gravity, 6.7 to 7.0. *Composition*: Molybdate of lead (26.1 per cent. of molybdenum). *Occurrence*: In veins with other lead ores.

*Ilsemanite*.—Colour, black to blue-black, becoming blue on exposure. Forms cryptocrystalline encrustations, and mammilated masses, occasionally earthy; soluble in water, to which it gives a deep cobalt blue colour. When molybdenite weathers to this mineral it becomes tinged with the same colour. *Composition*: Molybdate of molybdenum, an alteration product of molybdenite. Generally found with mineral sulphates in old mine workings. *Occurrence*: Associated with molybdenite in quartz vugs in the Lillian and Ridge claims at Bamford, Chillagoe District.

*Powellite*.—Colour, greenish, yellowish, and cream-coloured; lustre is resinous; subtransparent, fracture uneven. Forms minute, tetragonal crystals with a pyramidal habit; often silky, sub-fibrous, laminated and massive. Somewhat resembles scheelite when in a massive condition. Hardness, 3.5. Specific gravity, 4.5. *Composition*: Molybdate of lime (39 to 45 per cent. of molybdenum); sometimes pseudomorphous after molybdenite; generally contains tungstate of lime as a mechanical impurity. *Occurrence*: Associated with molybdenite and scheelite in quartz at the Sunny Corner Mine, Bamford; also found at Mount Benham, Kangaroo Hills Mineral Field, near Ingham, in association with molybdenite and wolfram.

*Pateraite*.—Colour, black; form, massive. *Composition*: Supposed to be a molybdate of cobalt.

*Molybdoferrite*.—Said to be a molybdate of iron. A molybdate of iron occurs at Bamford which is apple-green and submicaceous, and about 3 in hardness.

*Knightite*.—Said to be a phosphate of molybdenum.

*Chillagite* [Lyonite].—Colour, lemon yellow, pale yellow, brownish; transparent to translucent; lustre, vitreous to adamantine in basal planes, resinous on cleavages. Forms thin, tabular,

tetragonal crystals, with large basal planes and truncated edges, sometimes twinned. Hardness, 3.5. Specific gravity, 7.5; very brittle, fragile; cleavage, pyramidal. *Composition*: Considered to be a molybdo-tungstate of lead; analyses vary, and show a range between 10 and 14 per cent. of molybdenum. The mineral is an alteration product of wulfenite, the molybdate of lead evidently passing into stolzite, the tungstate of lead; more investigation is required before establishing it as a new mineral. *Occurrence*: Found in the Christmas Gift North Mine at Chillagoe in association with cerussite and minute crystals of pyromorphite, in a ferruginous clayey gossan contact deposit between granite and limestone, with lead, zinc, bismuth, and copper-bearing minerals in the vicinity.

*Eosite*.—Colour, deep red with orange yellow streak. Forms minute tetragonal crystals, square in section. Hardness, 3 to 4. *Composition*: Probably vanado-molybdate of lead. *Occurrence*: On crystals of pyromorphite and cerussite.

*Achrematite*.—Colour, pale yellow, orange, and red, with pale cinnamon-brown streak; translucent on thin edges; lustre resinous to brilliant. Hardness, 3 to 4. Specific gravity, 6.0; brittle; massive; cryptocrystalline. *Composition*: A mixture of molybdate, arsenate, and chloride of lead, with about 3 per cent. of molybdenum; forms as an alteration product of molybdenite when the latter is associated with other mineral compounds.

*Scheelite*.—Said to contain molybdenum as an impurity.

*Molybdosodalite*.—A variety of the silicate named Sodalite containing 1.3 per cent. of molybdenum.

### Prospecting and Mining.

Molybdenite, as stated previously, usually occurs as a contact mineral between two different geological formations, and white quartz outcrops without a trace of the mineral observable in them may be the cap of a rich lode. An examination may reveal some angular-shaped cavities from which tabular crystals or flakes of molybdenite have been partially or totally removed by weathering agencies, or otherwise may show the presence of surface-formed minerals resulting from the decomposition of molybdenite, such as molybdite or other minerals with which it is at times associated.

The utter barrenness and whiteness of a quartz outcrop of irregular dimensions with the cavities quite clean and empty are guides in some places to the presence of molybdenite at some

depth below the surface, provided that the mineral is known to occur on the field or in the neighbourhood.

In mining operations much the same general methods are adopted for the winning of the ore as with other mineral deposits when conducted in either a small or large way, although care has to be exercised in following the shoots of ore on account of their irregularity and because of the tendency to form ill-defined pipes which vary perhaps from two feet to twenty feet in diameter and may be very tortuous. When occurring with other metallic minerals it is not always possible to know that molybdenite is present either in the outcrop of a lode or some distance below the surface. It often associates, however, with wolfram and bismuth ores and, less frequently, with ores of tin, copper, zinc, arsenic, and gold, so that when these ores are found on the surface, oxidised or otherwise, then molybdenite might be looked for. Some molybdenite lodes pinch out without leaving a trace of ore to show where further to prospect; in others the molybdenite in the lode is found to gradually disappear in depth, and wolfram or bismuth, or perhaps copper, is met with, while occasionally there are alternations of molybdenite, wolfram, and bismuth in the one formation or lode.

There might be a high percentage of molybdenite in a lode, and the first impressions perhaps suggest the deposit being a valuable one, yet it may not be worth working on account of the contamination of the ore by some mineral from which the molybdenite would be difficult to separate, and many instances are recorded where all methods of treatment have failed to make the molybdenite product sufficiently clean for marketing. Copper pyrites and other mineral sulphides are not desirable, as they reduce the purity of a concentrate, but generally they can be removed either before the ore is concentrated or afterwards.

Amongst non-metallic impurities mica is perhaps the most objectionable, as its laminated condition prevents, to some extent, its separation from any associated molybdenite flakes. If, however, the mica is iron-bearing, much of it is removable in treatment. Silica is a common impurity which, however, presents no serious obstacles to its elimination.

If the value per ton of the molybdenite is known, and if the percentage of mineral in concentrate or clean ore has been estimated, a basis exists for determining the value of a deposit. If 1 per cent. of molybdenum sulphide is taken as the unit of value—this being the usual, although not invariably, the basis of the unit in ore valuing—and, say, 95 per cent. be the standard of quality, and £5 the value per unit, then the gross value per

ton of the mineral ready to be marketed can be shown to be £475. If the percentage of this clean mineral in the lode or deposit is known to be, say, 5 per cent. by assay or other test, then the quantity required to produce this gross value would be 19 tons, so that each ton of stone taken out of the lode would be valued at £23 10s. On the same basis one ton of stone containing one per cent. of molybdenum sulphide would be worth £4 14s.

The deductions made by ore buyers on account of the presence of injurious impurities in the mineral to be sold—such as phosphorus, bismuth, arsenic, copper, tin, or wolfram—will require to be considered, and also the deductions in the value per unit if the quality of the mineral is not up to the standard specified. These impurities and low percentages are sometimes so serious that buyers will refuse to take the mineral at any price, and a molybdenite deposit may be generally considered to be of very little value if the mineral obtained from it does not yield a concentrate containing over 85 per cent. of molybdenite, and then only when the impurities are not injurious, while 90 per cent. of molybdenite in the concentrate is sometimes the lowest which will be taken, consideration being given to the associated minerals making up the other 10 per cent. Bismuth and tin are commonly associated with the molybdenite in Northern Queensland, but the presence of half per cent. of each is not penalised.

### Concentration of Ores.

The removal of molybdenite from its gangue has frequently presented many difficulties to the miner, and until recently much of the fine flaky residual molybdenite mixed with mica and fine sand in tailings has remained a useless by-product. In a crude way the miner obtains the mineral by crushing the gangue with hammers or by dollying, and then picking out the flakes by hand or by dry sieving. Other more advanced methods entail the crushing of the ore, wet or dry, in mills consisting of rock-breakers, stamps, and rolls, and saving the powdered mineral in sieves and concentrators, or otherwise in reducing the whole of the ore to a fine grade and then treating it by some oil flotation process.

In the wet concentration of molybdenite sometimes the ore is crushed dry and subjected to a damping and then an exposure to air, by which a film of oxide is formed around any contained particles of undesirable sulphides, such as copper or iron pyrites, this operation removing any tendency they may have to float on the surface of water. The molybdenite flakes withstand this

oxidising action and remain unaltered, and as they float away are caught in suitable surface screens. If the concentrate thus obtained is not up to standard quality, it is put over table concentrators to eliminate any mineral having either a higher or lower specific gravity than the molybdenite; while an additional means of raising the quality is to put the concentrate through a magnetic separator to remove minerals containing iron. Bismuth is a common impurity in Queensland molybdenite ore, but it presents no difficulty in its removal except when it is interleaved as very fine flakes with the molybdenite, under which circumstances its elimination is sometimes impossible.

In oil concentration some experiments have shown that minute particles of oil will adhere to particles of molybdenite, and that if a number of these combined particles of oil and molybdenite are agitated in water they will rise to the surface and form a scum. In practice the ore may be crushed with hammers or by dollying, from which the large flakes are picked out by hand, the finer flakes being removed by intimately mixing the crushed ore with kerosene or eucalyptus oil and mechanically agitating it in water. The oil in the scum is dried out by any convenient means and the molybdenite is then ready for bagging. In the more refined processes machines are used for grinding and separating the ore, and the oil used is generally eucalyptus, the quantity of oil required being about half a pound to 1 ton of ore. The scum is dried, and the product, if sufficiently clean, is then ready for marketing, while if deleterious impurities are present further treatment will be required. The tailings may contain a small quantity of mineral, and circumstances will show whether this should be discarded or ground again and treated once more with oil.

Sometimes the operations are conducted in a vacuum pan, so that the atmosphere can be removed from the surface of the water and thus increase the buoyancy of the globules of oil and particles of molybdenite (Elmore Process). Occasionally acid is added to increase the cohesion of the oil and mineral, and if the gangue is made up in part of carbonate of lime the acid will generate gas bubbles which further accelerate the formation of scum on the surface. Sometimes both acid and carbonate of lime are added in the treatment, and the practice is said to work very satisfactorily.

To prevent the oil from adhering to particles of other mineral sulphides, such as iron pyrites, mispickel, or copper pyrites, the ore sometimes receives a preliminary roasting at a low temperature. This forms a film of oxide around the ore

particles and so prevents their adhesion to the oil, and allows of their settling to the bottom instead of being carried up with the oil to the surface. Care has to be exercised in roasting ores containing molybdenite, otherwise this mineral is converted into oxide, a compound which will not adhere to the oil.

Other means have been proposed to separate the fine molybdenite flakes from the quartz gangue, notably an air-blast process, by which the finely-crushed ore is driven along a flue, the fine, flaky molybdenite being carried a greater distance than the granular particles of other associated minerals, a receptacle for each product being arranged along the bottom of the flue. An electrostatic process has also been introduced, whereby the molybdenite, being a good conductor, can be separated from substances which are non-metallic and non-conductors. The process will not separate molybdenite from other metallic minerals, and to be effective all moisture must be removed from the ore by a preliminary drying operation. "Electrostatic processes will yield good results with all molybdenite ores to which they are suited and to which they are intelligently applied, and they are of particular value for treating ore that cannot be treated by flotation methods and on account of the absence of water supplies." (Horton.)

Another process combines a washing operation with a magnetic separation and oil flotation, any iron pyrites or copper pyrites present being made magnetic by the roasting and removed by a separator prior to the oil treatment.

### Metallurgical Notes.

Molybdenum, in one form, is a fused silvery-white metal, and in another form is a metallic crystalline powder of a dark blue colour. The first form is an electric furnace product and is practically free from all impurities, the powdered form, not so pure, being manufactured by a chemical process. The second condition of the metal is as effective as the fused product in the making of alloys, but in practice the absorption of this powder by the molten metal with which it is to be alloyed is attended with certain mechanical difficulties, and much of it is wasted.

Crude grey molybdenum, also an electric furnace product, is made direct from molybdenite, its composition being approximately 92 per cent. of molybdenum, 2 per cent. of iron, and 6 per cent. of carbon. It is very brittle and has a hardness greater than quartz, which it will scratch. This impure metal cannot be always used industrially, as the quantity of carbon present is objectionable, and necessitates a further fusion in an electric

furnace of the crude metal mixed with oxide of molybdenum, the oxygen of the latter combining with the carbon and forming a gas which is driven off.

In purifying this crude grey molybdenum from the iron, with which it is nearly always contaminated and which must not be present to the extent of more than 0.01 per cent. if the metal is to be used in the manufacture of fine filament wire, a series of fusions have to be made of it in the electric furnace at increasing temperatures up to 1,300 degrees C., with alternate crushings and sievings, by which all iron impurities are removed. Finally, the metal is subjected to a 100-ampere current to convert it into a homogeneous mass. This product will not change under ordinary temperatures, but will be slowly converted to oxide if subjected to a dull red heat. If the metal is repeatedly quenched after heating to 1,200 degrees C., its surface will become as hard as glass.

Experience has shown that in making very pure metal molybdic acid (oxide) and ammonium molybdate are the most satisfactory compounds to use, and in consequence electric furnace operators prefer that the natural sulphides be first converted into either of these compounds by chemical means.

When the metal is free from impurities it is softer than steel and can be worked into sheets, foils, or wire, the finest drawn wire made from pure metal, it is said, being 0.005 of an inch in diameter.

Ferro-molybdenum is an alloy containing from 50 to over 85 per cent. of molybdenum, and is made by fusing in an electric furnace certain proportions of the raw or roasted sulphide ore with iron scrap, lime, and fluorspar, together with anthracite or coke. Two typical analyses of the alloy made in this way and containing extreme amounts of the molybdenum and iron are as follows:—

#### FERRO-MOLYBDENUM ANALYSES.

	Per. Cent.		Per. Cent.
Molybdenum	50 – 85.8	Iron	49.30 – 10.96
Carbon	0.33 – 3.25	Silicon	0.30 – 0.11
Sulphur	0.03 – 0.05	Phosphorus	0.02 – 0.01

When made direct from the natural mineral the product, as in the manufacture of molybdenum, is not so pure as when made from artificial compounds, and generally contains excess of carbon and sulphur, both of which can be removed, either partly or wholly, by fusion with lime and oxide of iron.

Vanadium is also used with the ferro-metals and sometimes a few per cent. of this element is added to a molybdenum alloy.

Molybdenum-nickel is an alloy having a composition ranging from 50 to 75 per cent. of molybdenum, and from 25 to 50 per cent. of nickel, impurities in this alloy consisting of from 2 to 2.5 per cent. of iron, 1 to 1.2 per cent. of carbon, and 0.25 to 0.5 per cent. of silicon. Chromium and tungsten form important alloys with molybdenum, the chrome-molybdenum alloy containing about equal proportions of these two metals, and ferro-molybdenum-tungsten varying proportions of these three elements, with vanadium sometimes present to the amount of from 1 to 7 per cent.

The high temperatures at which the fusions take place in electric furnace processes cause much loss by volatilization, and sometimes only 70 per cent. of the metal used in each operation is usefully applied.

“Stellite” is the name of a series of alloys containing chromium and cobalt, with the occasional addition of molybdenum as a third element. One of the alloys is made by adding molybdenum in very small quantities to a cobalt-chromium containing 15 per cent. of the latter metal, the small addition of the molybdenum producing a certain degree of hardness, while with 40 per cent. of molybdenum the alloy is brittle and unworkable. The 25 per cent. alloy will take a hard, keen knife-edge, has a silvery lustre, and casts well, but cannot be worked or forged, while with 2.5 per cent. of molybdenum an alloy is produced which is tough and will scratch glass.

Molybdenum ores sometimes contain arsenic, bismuth, tungsten, and copper, and as the minimum amount of molybdenum which the metallurgists will allow is generally 85 per cent.—which is from 5 to 10 per cent. below certain standards—it is occasionally very difficult, or even impossible, to bring the ore up to this quality, and a high percentage ore may become valueless on account of such impurities. Lime and baryta are also deleterious substances when occurring in crude molybdenum, as their presence—even to the extent of 0.1 per cent. is said—prevents the metal being drawn into the form of fine wire.

### Uses of Molybdenum and its Alloys.

In metallurgical work the application of ferro-molybdenum with and without tungsten, nickel, and vanadium is very general in the manufacture of steels requiring great strength, toughness, elasticity, and self-hardening qualities; but practice has shown

that molybdenum is most effective when used as a minor constituent of the steel with tungsten. Considerable difficulty seems to be experienced in determining the right quantities of molybdenum to use in steels required for certain purposes, but it is recognised that in most grades the amount should be very small, and that the effective limit of range lies between 1 and 4 per cent. American metallurgists, however, have shown that some steels used for high-speed tools contain from 6 to 15 per cent. of molybdenum, and tools made of such steels are most effective when used at a dull red heat. Other high-speed steels have a composition of from 8 to 10 per cent. of molybdenum, between 2 and 3 per cent. of manganese, and nearly 2 per cent. of carbon. Stellite, referred to above, is not a carbon steel that has been treated with a ferro-alloy, and may be considered as an alloy which, to some small extent, takes the place of high-speed steels.

Chrome-nickel-molybdenum has been considered specially useful in motor-car construction, and in making fine boiler plates, rifle barrels, and parts of machinery subjected to alternate tension and compression, although present practice shows that the molybdenum is a subordinate constituent of the steel. It produces good results when used in the construction of heavy artillery, particularly in gun linings, the life of which is said to be extended considerably if the steel contains from 3 to 4 per cent. of molybdenum. Armour plates, propeller shafts, heavy cranks, and shells are other uses to which molybdenum-bearing steels are applied.

In the steel used in making permanent magnets it is found that from 2 to 3 per cent. of molybdenum in a chromium-carbon steel is better than the ordinary carbon steel, and a steel containing from 2 to 4 per cent. of molybdenum and from 10 to 60 per cent. of chromium, with a trace of carbon, is more or less acid proof; while a steel containing from 2 to 3 per cent. of molybdenum, 60 per cent. of chromium, and 35 per cent. of iron is proof against boiling nitro-hydrochloric acid.

The properties of molybdenum steels in common with other steels are affected by small quantities of other metals, considerable changes taking place in their behaviour, and further variations are produced according to the heat treatment they receive. Sometimes a difficulty is experienced in determining the right quantities of the metal to be used in a steel required to have certain properties, but it is recognised that in nearly all grades the amount of molybdenum must be very small and that the effective range varies between 1 and 4 per cent.

The metal in wire form is a valuable substitute for platinum,

particularly in connection with electric furnace fittings, in incandescent lamp filament supports, in X-ray work, in electrical ignition, and in arc lamp electrodes.

For jewellery purposes it is a good and desirable substitute for platinum, being as soft as steel, malleable, ductile, free from tarnish, permanent in lustre, of a beautiful colour, and capable of being worked like platinum itself.

In dentistry it is now being used as a substitute for platinum in the filling of artificial teeth, although when so used it is said to be covered or rolled with platinum.

### Chemical Compounds.

Molybdate of ammonia is the principal chemical compound made, and is commonly employed as a reagent in the chemical laboratory in the estimation of the phosphoric acid present in iron ores, steels, fertilisers, soils, &c.; while molybdenum trioxide is said to form a useful addition to mellinite powder, and that in another form molybdenum is used as a preservative for cordite.

Molybdate of soda will produce a blue colour in the dyeing of silks and woollens, and will give a blue colour to pottery glazes, although for the latter purpose cobalt compounds are said to be preferred. As a blue dye molybdenum indigo is used for colouring rubber, and molybdenum tannate will produce with logwood several shades of colour in leather, silk, wool, and rubber dyes.

### Production and Values.

In Table 36, showing the total production of molybdenite by countries, it is seen that Norway has produced the largest quantity of molybdenite "ore" in the world, while the production of Queensland is shown to be of the greatest value. In 1905 Norway produced 51 tons of ore having a greater value than the 1,129 tons yielded during the following year, and it is therefore assumed that the product for the year 1906 was made up of molybdenite and the matrix it was contained in. If this be so, then Queensland has produced both in quantity and value nearly one-third of the whole world's yield of molybdenite. United States has had a remarkable production of molybdenite within the last few years, due no doubt to the extraordinary war demand and the high prices prevailing exclusively in that country.

In addition to the returns given in Table 36, Japan in 1913 produced 3 tons of molybdenite, in 1914 between 4 and 5 tons, in 1915 about 10 tons, and in 1916 a little over 33 tons. The value of

the 1916 production was £6,495, or about £193 per ton, the values of other years' production not being known. Peru in 1915 exported 4 tons of 83 per cent. ore, in 1916 produced  $4\frac{1}{2}$  tons of similar quality, and in 1917 produced  $6\frac{1}{4}$  tons, the values not being given. Sweden in 1914 produced 7 tons; in 1915, 37 tons; and in 1916, 3 tons. Spain in 1915 produced about  $8\frac{1}{2}$  tons, and in 1916 about  $43\frac{3}{4}$  tons; while Bolivia in 1915 exported 6 tons (6,101 Kg.).

Table 37, showing the annual production of molybdenite by countries, indicates that within the last eight years the Queensland production was greatest in 1917, and that the 1918 yield was nearly as large. In values the yields of recent years are about three times that of 1911, and four or five times those of previous years. The United States production, owing to the fixing of the price of the mineral by the Imperial Authorities, unquestionably made great progress; and it will be interesting to see whether the large yields will continue now that the mineral can be sold in the open market.

Table 38, giving the annual production of Queensland from the year 1900, shows that the 11 tons produced in that year was valued at £561, or about £51 per ton; and that from 1905 to the present time the yields have fluctuated very much, with that of 1910 as the highest on record, so far as quantity is concerned.

TABLE 36.—TOTAL PRODUCTION OF MOLYBDENITE BY COUNTRIES, 1900-1919 (IN PART). (IN LONG TONS.)

Country Producing.	Years of Production.	Quantity.	Total Value.	Value per Ton.
		Tons.	£	£ s. d.
*Queensland .. ..	1900—1919	1,505·425	390,537	259 8 4
†New South Wales ..	1902—1919	759·00	197,058	259 12 7
‡Norway .. ..	1900—1916	1,522††	40,366	26 10 5
**Canada .. ..	1914—1918	401	201,690	502 19 4
§United States of America	1914—1918	1,191·67	431,981	362 10 0
		5,379·095	1,261,632	234 10 11

\* Statistical Table compiled from Wardens' Reports.

† Annual Report of the Department of Mines, New South Wales.

‡ Mines and Quarries (United Kingdom); Mineral Industry: and Engineering and Mining Journal (U.S.A.).

†† One-third of this quantity is probably crude ore produced in 1906, which accounts for the value per ton being low.

\*\* Mineral Production of Canada, 1917-1918.

§ Preliminary Report of the Mineral Resources of the United States in 1918.

TABLE 37.—ANNUAL PRODUCTION OF MOLYBDENITE BY COUNTRIES,  
1914-1919 (IN PART). (IN LONG TONS.)

Country Producing.	YEAR OF PRODUCTION.					
	1914.	1915.	1916.	1917.	1918.	1919.
*Queensland .. Tons	77·75	97·225	81·325	111·225	110·20	117·8
Value £	38,190	45,060	34,369	48,618	48,176	52,234
†New South Wales Tons	61·40	31·70	53·82	70·24	92·96	65·83
Value £	11,451	16,937	22,066	31,608	41,850	30,308
‡Norway .. Tons	70·0	85·0	98·0	..	..	..
Value £	3,600	4,300	5,000	..	..	..
**Canada .. Tons	1·7	13·04	69·84	147·46	168·96	..
Value £	430	6,025	39,232	66,668	89,335	..
§United States .. Tons	0·97	135·26	153·84	260·53	641·07	..
Value £	270	23,930	42,708	103,198	261,875	..

\* Statistical Table compiled from Wardens' Reports.

† Annual Report of the Department of Mines, New South Wales.

‡ Mineral Industry; Engineering and Mining Journal (U.S.A.); Mines and Quarries (U.K.).

\*\* Mineral Production of Canada, 1917-1918.

§ Preliminary Report of the Mineral Resources of the United States for 1918.

TABLE 38.—ANNUAL PRODUCTION OF MOLYBDENITE IN QUEENSLAND,  
1900-1919. (COMPILED FROM WARDENS' REPORTS.)

Year.	Total Quantity.	Total Value.	Value per Ton.
	Long Tons.	£	£ s. d.
1900 .. .. .	11	561	51 0 0
1901 .. .. .	26	1,609	61 17 8
1902 .. .. .	38	5,329	140 4 8
1903 .. .. .	10	1,320	132 0 0
1904 .. .. .	21·10	2,673	126 13 8
1905 .. .. .	63·25	8,496	134 6 6
1906 .. .. .	106·15	15,275	143 18 0
1907 .. .. .	66·65	8,442	126 13 3
1908 .. .. .	88·85	9,239	103 19 8
1909 .. .. .	93·75	9,268	98 17 2
1910 .. .. .	117·05	12,050	102 18 10
1911 .. .. .	99·50	13,278	133 8 11
1912 .. .. .	102·30	17,349	169 11 9
1913 .. .. .	66·30	19,001	286 10 2
1914 .. .. .	77·75	38,190	491 3 10
1915 .. .. .	97·225	45,060	463 9 3
1916 .. .. .	81·325	34,369	422 12 3
1917 .. .. .	111·225	48,618	437 2 3
1918 .. .. .	110·20	48,176	437 3 4
1919 .. .. .	117·8	52,234	443 8 3
	1,505·425	390,537	259 8 4

### Prices of Molybdenite and Ferro-Molybdenum.

The prices of molybdenite in London within the period 1914-1920, shown on Table 39, reached their maximum in February, 1915, and fell to their lowest in May, 1919, with a recovery in March, 1920. American prices in Table 40 have been converted from dollars to pounds sterling, the dollar being estimated at the value of 4s. 2d. A great difference existed between the English and American prices during the war owing to the official fixing of molybdenite prices by the Imperial Authorities for ore produced in Australia and Canada, one American quotation in 1917 being £1,398 per ton for 90 per cent. ore. During the period between September, 1915, and November, 1918, when the official price in London was 105s. per unit for 96-98 per cent. ore the American prices averaged 170s. per unit for 90 per cent. ore. At the beginning of 1920 London and New York prices still varied to some extent, although with the latter prices invariably higher than the English quotations.

Norway as a neutral country during the war of course was not bound by official prices—but the Imperial Authorities contracted to buy all her production up to June, 1918—and is said to have sold to the Allies ore having a value of £2,000 per ton. Now that conditions are somewhat similar to pre-war times some difficulty will be experienced by that country in maintaining an output, although the opinion has been expressed that production will continue so long as the price is not less than double that prevailing before the war.

In Queensland during the war period the prices paid for molybdenite varied with the locality, and officially recognised buying agents were appointed on the mining fields. The prices paid at mining and other centres were as follows:—Wolfram, £4 10s. per unit; Bamford, £4 11s. 1d.; Cairns, f.o.b., £4 11s.; Townsville, f.o.b., £4 12s. 6d; delivered in Sydney or Melbourne, c.i.f., £4 13s. per unit. These prices prevailed until August, 1917, after which a new arrangement was made to pay £5 per unit at any producing centre, and in March, 1920, six months after the declaration of peace, this also was cancelled, and at the same time the Imperial Government contract with the Commonwealth Government ceased.

London quotations for ferro-molybdenum are given in Table 41 and show that when first quoted in 1915 this alloy was worth 18s. per lb. (=£2,016 per ton), since which there has been a gradual decline in prices up to the end of 1919. The latest quotations to hand (April, 1920) show that an upward tendency exists even though there is very little, if any, difference

in the cost of the raw material. In the United States in 1919 there was the same decline in prices, at the beginning of the year the quotations being from 14s. 7d. to 18s. 9d. per lb., and at the end 10s. 5d. to 14s. 7d. per lb., in all cases being higher than those of London for the same period.

TABLE 39.—LONDON MOLYBDENITE QUOTATIONS, 1914-1920. \*  
(FOR 95-96 PER CENT. OF MOLYBDENUM SULPHIDE.)

	Price per Lb.	Price per Long Ton (96% ore.)
1914.—January .. .. .	6/-	£645
February .. .. .	3/9	£403
March .. .. .	4/9	£510
April .. .. .	5/6	£591
May .. .. .	4/8½	£506
June .. .. .	4/11	£528
July .. .. .	4/11	£528
September .. .. .	<i>Price per Unit.</i> 115/- — 120/-	£552—£578
December .. .. .	130/-	£624
1915.—February .. .. .	145/-	£696
March .. .. .	142/6	£684
April .. .. .	145/-	£696
May .. .. .	122/-	£590
July .. .. .	104/-	£500
September .. .. .	105/- (Official price fixed)	£504
1916.— .. .. .		
1917.— .. .. .		
1918.—November .. .. .	105/- — 120/-	£504—£576
December .. .. .		
1919.—January-April .. .. .	105/-	£504
May .. .. .	80/- — 105/-	£384—£504
June-December .. .. .	80/-	£384
1920.—January .. .. .	55/- — 80/-	£264—£384
February .. .. .	55/- — 100/-	£264—£480
March-April .. .. .	99/- — 100/-	£475—£480

\* "Daily Commercial Reports," London.

TABLE 40.—NEW YORK MOLYBDENITE QUOTATIONS, 1916-1920.\*  
(FOR 90 PER CENT. OF MOLYBDENUM SULPHIDE.)

Year.	Price per Unit.	Price per Lb.	Price per Ton (Long).
<b>1916.</b>			
February-March	131/- — 135/-	5/10 — 6/-	£588—£609
April .. .. .	131/- — 140/-	5/10 — 6/3	£588—£630
October .. .. .	140/- — 163/-	6/3 — 7/3	£630—£733
November-December	159/- — 173/-	7/1 — 7/8	£714—£777
<b>1917.</b>			
January .. .. .	167/- — 177/-	7/5 — 7/11	£752—£798
February .. .. .	168/-	7/6	£756
March .. .. .	168/- — 177/-	7/6 — 7/11	£756—£798
April .. .. .	186/- — 210/-	8/4 — 9/4	£840—£945
May .. .. .	310/-	13/10	£1,398
June .. .. .	186/- — 205/-	8/4 — 9/2	£840—£924
July .. .. .	196/- — 210/-	8/9 — 9/4	£882—£945
August .. .. .	196/- — 201/-	8/9 — 9/-	£882—£903
September .. .. .	196/- — 205/-	8/9 — 9/2	£882—£924
October-November	205/-	9/2	£924
December .. .. .	205/- — 214/-	9/2 — 9/7	£924—£966
<b>1918.</b>			
January .. .. .	205/- — 214/-	9/2 — 9/7	£924—£966
February .. .. .	201/- — 205/-	9/- — 9/2	£903—£924
March .. .. .	173/- — 205/-	7/8 — 9/2	£777—£924
April .. .. .	168/-	7/6	£756
May-June .. .. .	117/-	5/2	£525
July .. .. .	93/- — 117/-	4/2 — 5/2	£420—£525
August .. .. .	93/-	4/2	£420
September .. .. .	93/- — 117/-	4/2 — 5/2	£420—£525
October .. .. .	111/-	4/9	£499
December .. .. .	79/-	3/8	£357—£367
<b>1919.</b>			
January .. .. .	70/- — 79/-	3/- — 3/8	£315—£357
February .. .. .	75/- — 93/-	3/4 — 4/2	£336—£420
March .. .. .	75/- — 79/-	3/4 — 3/8	£336—£357
June .. .. .	61/- — 79/-	2/8 — 3/8	£273—£357
July-August .. .. .	70/- — 79/-	3/- — 3/6	£315—£357
September-December	70/-	3/-	£315
<b>1920.</b>			
January-March .. .. .	70/- — 79/-	3/- — 3/6	£315—£357

\* Engineering and Mining Journal.

TABLE 41.—LONDON FERRO-MOLYBDENUM QUOTATIONS, 1915-1920.†  
(FOR 70-80 PER CENT. MOLYBDENUM).

	Price per Lb.	Price per Ton.
*1915.—September .. .. .	18/-	£2,016
October .. .. .	17/- — 18/-	£1,904—£2,016
*1916.—April .. .. .	18/-	£2,016
May .. .. .	16/- — 18/-	£1,792—£2,016
June .. .. .	16/-	£1,792
July .. .. .	14/6	£1,624
August .. .. .	14/-	£1,568
December .. .. .	14/- — 15/-	£1,568—£1,680
*1917.—January .. .. .	14/-	£1,568
October .. .. .	14/-	£1,568
November .. .. .	14/6	£1,624
*1918.—January .. .. .	12/- — 14/-	£1,344—£1,568
February .. .. .	14/-	£1,568
March .. .. .	12/- — 14/-	£1,344—£1,568
August .. .. .	10/- — 12/6	£1,120—£1,400
September .. .. .	9/6 — 10/-	£1,064—£1,120
1919.—February .. .. .	9/6	£1,064
March .. .. .	9/-	£1,008
April .. .. .	9/3	£1,036
May .. .. .	9/- — 14/-	£1,008—£1,568
June .. .. .	12/- — 13/-	£1,344—£1,456
July .. .. .		
August .. .. .		
September .. .. .		
October .. .. .		
November .. .. .		
1920.—January .. .. .		
February .. .. .		
March .. .. .		
April .. .. .		

\* Prices are nominal.

† "Daily Commercial Reports," London.

### Conclusion.

The development of molybdenite deposits requires that consideration be given to the many geological conditions under which the mineral occurs and to the facilities which exist or may be created for mining it, and it would hardly be possible to decide whether a molybdenite mining proposition is payable or otherwise unless all the data concerning values and local conditions are known. However, with the prices shown on page 116 as a basis, and with due regard to fluctuations in the market value per unit, to form an estimate of what might be the value of an exposed part of a lode would not be a difficult matter. But fuel, freights, working capital, character of plant required, mining development, and impurities in the ore are other items to be considered, so that to determine what becomes a payable

proposition can only be decided by the merits of each particular case. Nevertheless, 1 per cent. of mineral in an ore under favourable conditions should pay cost of mining and treatment, but under adverse circumstances 10 per cent. might not be profitable to mine.

The areas of mineral-bearing country in Queensland in which the prospecting for molybdenite might be carried on are certainly very extensive. Large tracts of granite country exist in the Chillagoe and Herberton Mineral Fields which have only been superficially explored and which are probably mineral-bearing from one end to the other. There is another granite area further north on the eastern side of Cape York Peninsula which has not been examined for molybdenite, although the prevailing conditions are favourable for its occurrence, as many other associated minerals, including wolfram, are to be found there. This area extends from the Alice River at about the centre of the Peninsula west of Cooktown to Temple Bay, a distance of about 200 miles, and, as it is so little inhabited, prospecting operations are best undertaken by expeditions well equipped and prepared for a campaign of from six to eighteen months, with Princess Charlotte Bay or Ninian Bay as a base. Then there are the granite areas of Croydon, Etheridge, Bowen, Broadsound, Burnett, Eidsvold, and Stanthorpe, and many other places.

The quantity of the molybdenum sulphide necessary to make 1 ton of ferro-molybdenum is said to vary from  $1\frac{1}{2}$  to  $1\frac{2}{3}$  tons, according to quality. The price of the mineral now (July, 1920) is about £480 per ton, and one ton of the ferro metal would require a quantity costing not more than £672, but as the price of ferro-molybdenum is at least £1,344 per ton the manufacturer's profits and costs would therefore be about equal to the cost of the raw material. Queensland and New South Wales together produced in 1919 a little over  $183\frac{1}{2}$  tons of molybdenite valued at £82,543; and this would make at least 131 tons of ferro-molybdenum, valued at over £176,000, representing about £90,000 in manufacturer's costs and profits for one year only, or over 100 per cent. on the costs of the mineral delivered in London.

The sending of molybdenite to oversea markets as raw products instead of molybdenum and ferro-molybdenum as finished products is a matter on which opinions vary, but there seems to be very little difference between the conditions prevailing before the war between Germany and England, so far as the manufacture of molybdenum is concerned, as there is now between the Commonwealth and England. As its manufacture

has been accomplished in the latter country in spite of all difficulties and all the secrecy concerning its manufacture, there seems to be no reason why a further step should not be taken to produce it within the Commonwealth. It is also being made in France and Italy where there are no deposits of the mineral to operate upon, and works are now established in the United States and in Canada and Norway, where ore supplies are limited, while the Commonwealth is without a treatment works—and at the same time supplies the bulk of the ore to keep the outside works going. It could not be said that conditions are favourable for the cheap manufacture of ferro-metals in Australia, but that is a small consideration when taken in conjunction with the fact that as a direct result of treating ore obtained from us some firms make nearly £100,000 every year, a direct result of not having works of our own to treat this one mineral.

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# Article 5.—PLATINUM GROUP METALS.

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## Article 5.—PLATINUM GROUP METALS.

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### Queensland Localities.

Very little attention has been given to the occurrence of platinum in Queensland, and notwithstanding the fact that conditions are favourable for its presence in many localities, very few discoveries of the metal have been made. For a long time it has been known to be associated with osmiridium in the beach sands between Southport and Currumbin, on the South Coast, and also in some of the creeks on the Russell Goldfield, near Innisfail. It has also been found in the alluvial deposits of Brickfield Gully and in the Lady Mary and Alma Reefs on the Gympie Goldfield. To these other localities have to be added, as it has been learned that alluvial platinum was found many years ago at the head of the Don River, in Central Queensland, at a position about 30 miles south from Mount Morgan and about 20 miles above the junction of this river with the Dee River, and also in Fat Hen and Angella Creeks, near Kilkivan.

### Other Localities.

Within the Commonwealth the metal has been found in New South Wales, Victoria, and Tasmania. The New South Wales deposits are situated principally at Fifield, Broken Hill, Platina, and about the Tweed and Richmond Rivers, on the North Coast, while it is also said to occur at the head of the Tumut River. In Victoria the most important occurrence is in the Walhalla Copper Mine.

The principal platinum deposits of the world are in the Urals of Russia, the next in importance being those at Choco, of Colombia, in South America. Other producing countries include the United States, Borneo and Canada, but the metal is also known to occur in New Zealand, New Caledonia, Santo Domingo in the West Indies, Japan, Burma, Algiers, Madagascar, Spain, Mexico, Honduras, French Guiana, Brazil, Alaska, California, British Columbia, Philippines, Sumatra, Dutch East Indies, Norway, India, Westphalia, Lapland, and Griqualand in South Africa.

Osmiridium (iridosmine) has also been found in Tasmania, New South Wales, Russia, Colombia, Brazil, Santa Domingo, United States, and British Columbia, but the quantities obtained so far are very small except in the first-mentioned locality, where the yields from the fields at Mount Stuart and at the Savage and Wilson Rivers have been phenomenal. On the New South Wales northern coast the mineral occurs on the beaches about the Richmond and Tweed Rivers, *i.e.*, Evan's Head and the vicinity of Ballina, the deposits being a continuation of the osmiridium-bearing sands about Currumbin, further north on the Queensland coast.

### Minerals Containing Platinum Metals.

*Native Platinum.*—Usually occurs in very fine grains, more or less flattened, seldom with crystalline faces; colour varies between tin-white and steel-gray; ductile, sometimes magnetic. Hardness—4 to 4.5; can be scratched with a knife; specific gravity—16 to 19, according to composition. Infusible except at a high temperature, such as that of the oxy-hydrogen flame. Composition—platinum, with varying quantities of iron, copper, iridium, osmium, palladium, rhodium, ruthenium, and gold. See Table 42.

*Iron Platinum.*—Some of the Urals platinum is polar-magnetic and occasionally this property is more pronounced than the polarity in an ordinary horseshoe magnet. This property is only developed in platinum containing a high percentage of iron, although many platinites containing iron are not magnetic, as shown in the analyses in Table 42.

*Platiniridium.*—Has many of the characters of platinum, but its hardness is greater—between 6 and 7—and the specific gravity is higher—between 22.6 and 23. In composition it has been observed to contain from 27.79 per cent. to 76.80 per cent. of iridium. See Table 42.

*Osmiridium.*—Occurs as irregular flattened grains, sometimes with faceted edges and cleavage faces; colour and lustre similar to platinum. Hardness—6 to 7 (scratches glass); usually malleable, sometimes brittle. Specific gravity—19 to 21 (about equal to platinum). Infusible at ordinary temperatures, but fuses and gives off odour of osmium gas at high temperatures. *Composition:* Varies from 21 to 57 per cent. of osmium and from 33 to 77 per cent. of iridium. Table 43 shows the composition of a number of osmiridium varieties.

TABLE 42.—COMPOSITION OF NATIVE PLATINUM AND PLATINIRIDIUM.

Locality.	Pt.	Fe.	Pd.	Rh.	Ir.	Os.	Cu.	Os-Ir.	Remarks.
<i>Platinum.</i>	%	%	%	%	%	%	%	%	
Urals 1*... ..	76.22	17.13	1.87	2.50	tr.	..	0.36	0.50	Magnetic grains
Urals 2 .. ..	73.58	12.98	0.30	1.15	2.35	tr.	5.20	2.30	Magnetic grains
Urals 3 .. ..	81.34	11.48	0.32	2.14	2.42	tr.	1.13	0.57	Non-magnetic
Urals 4 .. ..	78.94	11.04	0.28	0.86	4.97	..	0.70	1.96	Non-magnetic
Urals 5†... ..	90.16	6.26	1.18	1.32	0.33	0.18	0.38	..	Non-magnetic
Borneo .. ..	82.60	10.67	0.30	..	0.66	..	0.13	3.80	Gold, 0.20 per cent.
Brazil .. ..	72.62	tr.	21.82	..	0.88	..	..	..	Sand, 0.42 per cent.
Granite Cr., B.C.	68.19	7.87	8.26	3.10	1.21	..	3.09	14.62	Gangue, 1.69; non-mag.
Granite Cr., B.C.	78.43	9.78	0.09	1.70	1.04	..	3.89	3.77	Gangue, 1.27; magnetic
Choco, Col. ..	86.20	7.80	0.50	1.46	0.85	..	0.60	0.85	Sand, 0.95
Choco, Col. ..	84.30	5.31	1.06	3.45	1.46	1.03	0.74	..	Gold, 1.0; sand, 0.61.
California ..	85.50	6.75	0.60	1.00	1.05	..	1.40	1.10	Gold, 0.8; sand, 2.95
California ..	79.85	4.45	1.95	0.65	4.20	..	0.75	4.95	Gold, 0.55; sand, 2.69
Oregon .. ..	51.45	4.30	0.15	0.65	0.40	..	2.15	37.30	Sand, 3; Gold, 0.85
Fifield, N.S.W...	75.80	10.15	tr.	1.30	1.30	..	0.41	9.30	Gold, nil; sand, 1.12
"Australia" ..	61.40	4.55	1.80	1.85	1.10	..	1.10	26.00	Gold, 1.2; sand, 1.4
Curumbin, Q...	26.12	27.17	..	..	..	..	2.51	40.02	Sand, 1.33
<i>Platiniridium.</i>									
Condado, Brazil..	55.44	4.14	1.49	6.86	27.74	tr.	3.30	..	
<i>Native Iridium.</i>									
Urals .. ..	19.64	..	0.89	..	76.80	..	1.78	..	

Reference—Pt, platinum; Fe, iron; Pd., palladium; Rh, rhodium; Ir, iridium; Os, osmium; Cu, copper; Os-Ir, osmiridium.

\* Average percentage of Urals platinum is a little under 80.

† Highest percentage of platinum recorded. The lowest is 64.65 %.

*Platinum Nuggets.*—The analyses of some of the nuggets found in alluvial deposits show that chromite generally forms part of their mineral composition, and that pyroxene and olivine are occasionally present. Nuggets found at Tulameen, in British Columbia, sometimes contain as much as 40 per cent. of chromite, and pieces have been found in the deposits coated with gold in such a manner as to suggest that the deposition of the gold film must have taken place since the nuggets became waterworn. The largest specimen of platinum yet discovered weighed 25 lb. 10 oz., and was obtained from the Urals at Nishne Tabliske. Others have been found in the same locality which weighed 21 lb. and 11½ lb. respectively, and a specimen obtained at Choco, in Columbia, contained 2 lb. 6 dwt. 8 gr., the size being 2 in. by 2 in. by 4 in., while another from the same place weighed 2 oz. 5 dwt. 8 gr. At Oberon, in New South Wales, in an alluvial deposit, a nugget was found which weighed 11 dwt., and a small nugget was found at Gympie in association with alluvial gold.

TABLE 43.—COMPOSITION OF OSMIRIDIUM VARIETIES.

Varieties and Localities.	Ir.	Os.	Pt.	Ru.	Rh.	Other Elements, &c;
	%	%	%	%	%	
<i>Nevyanskite</i> —						
1. Urals ... ..	77.20	21.00	1.10	0.20	0.50	Cu, <i>trace</i>
2. California ... ..	53.50	43.40	...	0.50	2.60	
3. Borneo ... ..	58.27	38.94	0.15	...	2.64	
4. Currumbin, Q.* ...	62.00	33.00	3.00	...	...	Gangue, 2%
<i>Platinum Nevvanskite</i> —						
5. Urals ... ..	55.24	27.23	10.08	5.85	1.51	Pd, Fe, Cu, <i>trace</i>
<i>Ruthenium Nevvanskite</i> —						
6. North Coast, N.S.W.	58.13	33.46	...	5.22	3.04	Cu, 0.15
7. Colombia ... ..	57.80	35.10	...	6.37	0.63	Fe, 0.10 ; Cu, .06
8. Urals ... ..	43.94	48.35	0.14	4.68	1.65	Fe, 0.65 ; Cu, 0.11
9. Tasmania ... ..	46.12	25.22	0.13	9.24	4.37	Pd, <i>trace</i> ; Fe, 6.3 ; Au, 3 ; Sand, 3.71
<i>Rhodium Nevvanskite</i> —	64.50	29.90	2.80	...	7.50	Fe, 1.40 ; Cu, 0.9
10. Urals ... ..	70.40	17.21	0.10	...	12.30	
11. Colombia ... ..	33.80	57.09	0.37	8.19	†	
<i>Sisserskite</i> —						
12. Tasmania ... ..						Pd, 0.21 ; Au, 0.14 ; Fe, 0.3 ; Cu, <i>trace</i> ; Sand, 2.

\* Queensland Geological Survey Museum Sample.

† Included in iridium.

*Black Platinum.*—Sometimes the alluvial platinum grains are coated with a black film of iron oxide, and then are not easily recognisable, more particularly if the platinum is magnetic, but if gold is also present in a wash the black grains will be found to be heavier, and if a trial is made in a prospecting dish with water the black grains will sink to the bottom below the gold. Acids will not always remove the coating, but rubbing with a hammer in the dish is usually sufficient to expose the platinum lustre. No doubt the film is due to the oxidation of the metallic iron which almost invariably is present in the native platinum.

*Nickelliferous Platinum.*—This is a platinum occurring in the Urals containing 0.75 per cent. of nickel and 8.18 per cent. of iron. It is magnetic even though the percentage of iron is much lower than that of any other native platinum, a result probably due to the presence of the nickel.

*Colloidal Platinum.*—This has only recently been detected in ores, and therefore might occur without giving a qualitative test of its presence. By destroying its colloidal condition, however, its presence can be detected in the ordinary ways.

*Palladium*.—Generally resembles platinum in appearance, usually in grains, but sometimes occurs fibrous and in minute octohedrons. Hardness—4.5 to 5; specific gravity—11.5. Composition—palladium, with a small percentage of platinum and iridium. Malleable.

*Palladium-Gold*.—"Oura Preto" is one variety of this mineral containing, according to Seamon, 91.06 per cent. of gold, 8.21 per cent. of palladium, and traces of silver and iron. "Porpezite" is another variety containing 85.98 per cent. of gold, 9.85 per cent. of palladium, and 4.17 per cent. of silver, both varieties being found in Brazil. (Kemp.)

*Platinum-Gold*.—This native alloy is found in a quartz reef at the Pas, Manitoba, and in quartz at Burnt Ridge, British Columbia.

*Allopalladium* (Eugenesite).—The allotropic form of palladium, crystallising in hexagonal crystals. Composition—palladium with gold and silver. Colour—silver-white to pale steel-grey. Said to be of exceedingly rare occurrence. Found on gold in association with selenides of lead and mercury, in a quartz-dolomite-calcite matrix in the Hartz, Germany.

*Sperrylite*.—Occurs as minute cubical or octohedral crystals; colour, tin-white; streak, black; lustre, metallic and brilliant; brittle, with conchoidal fracture. Hardness—6 to 7; specific gravity—10.6. Composition—56.5 per cent. of platinum and 43.5 per cent. of arsenic.

*Platiniferous Chromite*.—The association of both chromite and platinum with serpentine is so common that the recording of a chromite deposit in South Africa containing 1 dwt. of platinum to the ton does not come as a surprise, but nevertheless is interesting. Recently, at Beaume, in Ontario, another chromite deposit has been found to be platinum-bearing.

Investigations have shown that when platinum and chromite are subjected to great heat, the platinum fuses first, and it is therefore contended that the chromite crystallised out from the magma before the platinum.

*Nickeliferous Pyrrhotite*.—Ore containing this mineral at the Insizwa Range, in Griqualand, South Africa, has been tested, and the assays show the presence of copper, nickel, and platinum. It has been noted throughout the world that the metals of the platinum group, together with gold and silver, appear to be present in pyrrhotite in at least small quantities when nickel also is present in the mineral.

*Plumbojarasite*.<sup>\*</sup>—A lead-iron sulphate containing bismuth, and having the appearance of a greenish tale, occurs at the Boss Mine, Nevada. It is said to contain a high percentage of gold, platinum, and palladium, and is considered to be an alteration product of some such mineral as bournonite. By some observers, however, plumbojarasite is thought to be the result of an alteration of galena in the presence of ferric sulphate, and that the gold, platinum, and palladium were deposited at the time of the alteration.

*Laurite*.—A sulphide of ruthenium with a small percentage of osmium. Crystallises in small cubo-octohedrons. Hardness—above 7. Specific gravity—6.99. Lustre—metallic. Colour—iron-black. Powder—dark-grey. Brittle. Very rare. Only known to occur in Borneo.

*Bournonite*.—A sulphide of lead, antimony, and copper. Platinum occurs in this mineral in a dolomitic matrix at St. Arey, near La Mure, France.

*Tetrahedrite*.—A sulphide of antimony and copper. Platinum is found in an argentiferous variety of this mineral in association with malachite in a locality near Presles, in Savoy, France. Platinum is also found in tetrahedrite, associated with metamorphic rocks at Chartelard, Valle du Drac, Hautes Alps, and at Rio Tinto, Spain.

*Chalcocite*.—A sulphide of copper. In the Boss Mine, Nevada, this mineral is reported to contain 15.1 per cent. of copper, with 0.40 oz. of platinum metals, 0.13 oz. of gold, and 1.2 oz. of silver to the ton.

### Geological Features.

Nearly all the platinum produced in the world has been obtained from alluvial (placer) deposits, only a very small quantity coming from lodes. Most of the platinum occurring in these alluvial “leads” has had its source in serpentine, peridotite, gabbro, diorite, or other dyke rocks of a basic character, and only occasionally has it been derived from formations in schistose or altered sedimentary rocks.

In serpentine it appears to be finely disseminated in the rock itself, and seldom in any lode formation, although chromite deposits in serpentine have occasionally proved to be platinum-bearing. In altered sedimentaries, such as schists and slates, it occurs in quartz and iron-bearing lodes, its geological associa-

<sup>\*</sup> A gold-platinum-palladium lode in Southern Nevada. By A. Knopf. U.S. Geol. Survey Bull. 620A, 1915.

tions being the same as those of gold. Some geologists are of the opinion that, so far as its occurrence in deep ground is concerned, the metal has been deposited or crystallised out from the original molten rock, while others consider that it has been introduced as a chloride of platinum in the form of vapour and subsequently reduced to the metallic state.

The minerals associated with platinum are numerous and varied in character, the lode minerals being quite distinct from those occurring with the metal in serpentine areas, so that an examination of a "lead" or a beach sand will often indicate the source of the metal. In the serpentines and peridotites the associated minerals are usually chromite, magnetite, ilmenite, iridium, and osmiridium; while in the schists and slates the chromite is not present, the commonly associated minerals containing copper, nickel, silver, and palladium. Osmiridium occurs in much the same way as platinum, and its associated minerals and rocks, so far as investigations have gone, are the same as those found with platinum.

The metallic minerals occurring with platinum metals in lode deposits include—bornite, bournonite, copper pyrites, chalcocite, covellite, malachite, copper vanadate; pyrites, ilmenite, mispickel, hematite, magnetite, limonite, siderite, titanite, nickeliferous pyrrhotite; galena, lead vanadate, pyromorphite, plumbojarasite; chromite, laurite, polydymite, porpezite, sperrylite, oura preto, osmiridium, palladium, native gold, platinum-gold, and allopalladium.

The non-metallic minerals found in lode deposits comprise—apatite, calcite, barytes, magnesite, dolomite, hornblende, enstatite, hypersthene, olivine, garnet, and quartz.

The rocks in which platinum-bearing lodes have been known to occur include—diorite, grano-diorite, gabbro, norite, hornblende rock, hypersthene, pierite, dunite, peridotite, serpentine, augite-syenite, granite, pegmatite, quartz porphyry, gneiss, schists, limestones, dolomites, quartzites, and sandstones.

The minerals present in beach sands vary according to local circumstances, but chromite and magnetite are very common, while gold, tinstone, diamond, garnet, zircon, tourmaline, corundum, topaz, and monazite are also known to be present.

In alluvial deposits a variety of minerals are found with the platinum, the rocks shedding the metal being usually in the same area as those containing other minerals, and all concentrating their products into the same alluvial formation. Thus platinum, which has not yet been found associated with gold in

serpentine, may with its accompanying minerals exist in a "lead" or beach deposit with gold, each having been derived from separate and distinct classes of rock.

Amongst the metals of the platinum group there seems to be a fairly uniform occurrence of platinum with iridium or osmiridium in serpentine country, gold being conspicuous by its absence; while platinum in altered sedimentary rocks is usually found to occur with palladium and gold. In alluvial and beach deposits, therefore, the presence of palladium and osmiridium, (or iridium) would be indicative of the source of the platinum, and this could be confirmed by the presence or absence of chromite, the mineral so persistently occurring in serpentine.

The Ural deposits of platinum, the principal of which are to the north-north-west of the town of Ekaterinburg, are all alluvial formations, and the source of the platinum is in country made up of serpentine, gabbro, diorite, diallage, and olivenite. The associated minerals include quartz, zircon, ilmenite, chromite, magnetite, spinel, native gold and native palladium. The gold sometimes contains silver, but the latter metal is generally combined with the palladium, while the native platinum usually includes some iridium, rhodium, ruthenium and iron. The platinum in the Urals appears to have had two sources, one in a serpentine area, the other in a neighbouring formation made up of schists and other altered sedimentary rocks.

In Spain platinum has been discovered at Sierra del Ronda, in the Malaga District near Gibraltar, where the prevailing rocks are serpentine and peridotite, as in the Urals. The metal is found in alluvial deposits formed from the disintegration of these rocks and is always associated with chromite. Near Rio Tinto platinum occurs in mica schist in an ore made up of tetrahedrite contained in a quartz-calcite-barytes gangue.

At Chatelard, in the Valle du Drac, Hautes Alps, France, the metal is found in metamorphic limestone, the gangue being dolomite, barytes and quartz, and the ore tetrahedrite.

In Westphalia, where the deposits are said to be extensive and give promise of great developments, the ore contains platinum, lead, zinc, antimony, and nickel. The aggregation of the minerals is very complex, and the metallurgical treatment in consequence is said to be very difficult. In Lapland, on the Ivalo River, platinum has been found associated with chromite and diamonds in an alluvial deposit, its source being considered to be the serpentines occurring in the district, while in Southern Finland it is found in a lode formation containing quartz,

siderite, calcite, and dolomite, with a small quantity of gold and oxides and carbonates of copper and iron.

In Borneo the rocks of the Bobaris Mountains consist of gneisses and schists intruded by serpentine, gabbro, and diorite dykes, and platinum has been found in the beds of streams flowing from this country. Platinum, osmiridium and gold occur in the gravels, sometimes the platinum and gold being found in specimens so closely associated as to leave no doubt about the matrix being common to both.

In Sumatra the platinum has been found in limestone and schist near intrusions of grano-diorite and augite-diorite, with garnet rock, bornite, and wollastonite formed at the contact. Copper deposits consisting of bornite and copper pyrites exist in this contact zone, and where the wollastonite is decomposed there are appreciable quantities of platinum, gold, and silver, but where the copper is present in the ore the platinum is absent.

In Brazil, at Antioqua, platinum occurs closely associated with gold in gravels derived from the denudation of lodes in diorite. It is in association with palladium, silver, covellite, copper pyrites, iron pyrites and tetrahedrite, and evidently is in the metallic condition or as an arsenide, the palladium being an accessory metal in the tetrahedrite. At Candonga a palladium-gold has been found in a lime-silicate rock at the junction of limestone with granite and pegmatite masses.

In Belgian Congo a gold-bearing sandstone in a sedimentary series of sandstones and quartzite has been found to contain platinum, with silver and palladium also present, all these minerals being in a metallic state. Other associated minerals comprise malachite, pyromorphite, and vanadates of lead and copper.

In British Columbia there are platiniferous sands and gravels on the Tulameen River and at many other localities to the east of Vancouver. The platinum is associated with magnetite, chromite, and olivine, and the deposits are sometimes 70 ft. thick. The source of the metal is dunite and pyroxenite, and where in these rocks the chromite occurs the alluvial deposits in the vicinity are found to be richest. In this Province the platinum is found in lode formations associated with chromite and serpentine, also in sheer zones in granite, and in various kinds of deposits containing copper pyrites. (O'Neill.)

In Yukon the platinum is found combined with alluvial gold, and reports indicate that the metal is widely distributed,

although up to the present it has not been found in payable quantities.

The Sudbury nickel deposits of Ontario are in a sedimentary series of rocks penetrated by norite, a variety of gabbro. The platinum in this lode is in the form of an arsenide closely associated with sulphides of iron, nickel, and copper, with gold, silver, and palladium also present, and iridium and chromite absent. The platinum appears to favour the ores rich in copper, while most of the palladium is found in the rich nickel-bearing portions (Ontario Nickel Commission's Report). The platiniferous chromite found in this Province at Raume in association with chromite has already been referred to.

The Choco platinum deposits on the San Juan, Atrato, and Pinto Rivers of Colombia, next in importance to those of the Urals, are alluvial formations in serpentine. The native metal has actually been found in this rock, which, there appears to be no doubt, is its matrix. Granite of varying composition is also found in the neighbourhood traversed by quartz lodes containing palladium, iridium, osmium, and rhodium, the first-mentioned being the principal metal.

In the Boss Mine, Clarke County, Nevada, platinum occurs in association with gold and platinum in a bismuth-bearing plumbojarasite, the ore itself being in a fine-grained siliceous formation. Closely connected with this deposit is another ore containing copper in an oxidized condition, the two deposits, in the form of nearly vertical shoots, being in beds of dolomite—of which the siliceous formation is a replacement—with intrusive granite porphyry and quartz monzonite porphyry in the vicinity.

In California and Oregon platinum is recovered as a by-product in alluvial gold-mining operations, and is derived from serpentine, peridotite, and gabbro masses. (Knopf.)

In New Zealand platinum has been found under a variety of conditions, amongst which it is recorded as occurring on the Thames River in a region of serpentine and diorite in quartz lodes, and also at Westland in similar country in a pyritic lode.

In Victoria a platinum-bearing deposit has been worked at Platina, close to the town of Walhalla in the Gippsland District. The metal occurs in a hornblende matrix in diorite, in association with gold, silver, and copper pyrites. The diorite intrudes a series of slates with limestone in the vicinity.

In Tasmania platinum deposits have not yet been proved to exist, although it is obtained in the refining of blister copper,

but the osmiridium deposits occurring on the Savage River (Bald Hills), Wilson River, and other fields are in areas of serpentine, the mineral being in the form of nuggets and fine grains in alluvial deposits with magnetite and chromite, and close to the boundary of sedimentary rocks and the intrusive serpentine. Some of the osmiridium has been found in the serpentine rock coated with a black pigment, and when isolated from the matrix has the appearance of a black sand. Mr. A. I. Reid, Assistant Government Geologist of Tasmania, has been examining the osmiridium fields, and kindly furnishes the following extract taken from a work which he has in preparation:—

“The occurrence of bronzite, enstatite, and olivine in peridotites, pyroxenites, and gabbros—or in serpentine resulting from the decomposition of these rocks—is considered to be favourable for the presence of osmiridium, while monoclinic pyroxenes, such as augite and diallage appear to be limited to rocks barren in osmiridium. The deposits containing osmiridium are almost exclusively confined to differentiation streaks or “schlieren” in structural planes developed in the rock, and not only is it possible to distinguish the osmiridium-bearing serpentines from those that are barren, but the precise location of the deposits in these rocks can be fixed without difficulty. Other interesting features are the presence of chrome spinel in the serpentines and the high percentage of alumina in bronzite.”

In New South Wales platinum-bearing lodes have been recognised at Mulga Springs Creek, situated near Broken Hill, the metal being in a copper-nickel gossan closely associated with gabbro and decomposed gneisses and schists. It has been considered to bear some resemblance to the Sudbury deposits referred to above.

At Fifield and Platina,  $1\frac{1}{2}$  mile apart, and 54 miles north-west of Parkes in New South Wales, there is an occurrence of alluvial platinum which is the most important deposit of its kind in the Commonwealth. The rocks about the “lead,” which is one and the same in the two localities, are mostly slates, and the platinum in association with osmiridium and gold is in a gravelly wash. Apparently there is nothing to indicate the character of the rocks from which these minerals have been shed, but one specimen has been found which contains both native gold and native platinum so associated that they must have had a common matrix, and this rather suggests their source to have been outside a serpentine area.

At Gympie, the Lucknow and Alma gold-bearing reefs many years ago yielded a few platinum specimens, but no attention was then given to the occurrence. The metal occurred in a quartz lode with native gold and mispickel, the associated rocks being purple and black slates alternating with volcanic tuffs and conglomerates. In the vicinity of these reefs the platinum has also been found in rich gold-bearing alluvial deposits, and one specimen is said to have weighed several dwts.

The beach sand deposits containing platinum, gold, and osmiridium at Ballina, close to the mouth of the Richmond River, at Evan's Head further south, and also at Currumbin near the mouth of the Tweed River further north, accumulate along the beaches during stormy weather, and are covered by other sand deposits when weather conditions become normal.

All these black sands contain gold, tin, monazite, platinum, and osmiridium in exceedingly fine grains and in association with topaz, zircon, garnet, tourmaline, ilmenite, magnetite, chromite, and sapphire. The sources of these minerals are problematical, but the platinum and osmiridium appear to have been derived from the serpentine area which forms, in part, the western edge of the Clarence Coal Measures, and which is only to be observed now as fragmentary outcrops, while the gold, tin, and monazite might have had their origin in the granite and other rocks of the New England Tableland.

Possibly in former times the platinum and other minerals, each from their individual source, were accumulated in the sediment forming the Clarence Series of rocks, and which natural agencies are now redistributing in the coastal sands. Along this coast the disposition of sand is northerly from the rivers bringing the material down from the high lands, and this suggests the idea that the sources of the minerals are always south of the beach deposits in which they happen to occur. Some of the Currumbin sands, indeed, have been found to contain chromite, which rather indicates the serpentine to be the source of some of the minerals contained in them.

At Ballina and Evan's Head the platinum is the predominating mineral in the sands, with gold only in small quantities, while at Currumbin, further north—and further from its source—the platinum is only in traces, with the gold in greater quantities.

In California and Oregon platinum is found on the beach sands of the Pacific coast, and evidently under similar conditions to those at Ballina and Currumbin. The minerals associated with it include chromite, ilmenite, magnetite, olivine, monazite, rutile, corundum, garnet, and topaz.

*Summary.*—Generally considered, the different types of platinum deposits can be conveniently placed in six groups or divisions, in which there exists some variations, however, due to differences in mode of occurrence. These divisions are as follows:—

1. Copper-nickel deposits in basic eruptive rocks.
2. Chromite deposits and associated formations in dunite and serpentinous rocks, with or without osmiridium and iridium.
3. Siliceous lodes in sedimentary, metamorphic, and eruptive rocks of a hornblendic character, and with or without copper pyrites, iron pyrites, tetrahedrite, bournonite, pyrrhotite, gold, and palladium—chromite being absent.
4. “Leads” or “placers” in serpentine country, where the platinum is associated with iridium, osmiridium, chromite, and olivine.
5. Leads or placers in altered sedimentary rocks, where the platinum is associated with minerals containing palladium, gold, silver, copper, and nickel—chromite being absent.
6. Beach deposits near the entrance of rivers draining (*a*) serpentine areas or (*b*) altered sedimentary rocks.

### **Mining Operations and Metal Values.**

The mining of platinum-bearing gravels is conducted in very much the same way as gold mining, and the recovery of the platinum in sluices, dredges, &c., follows on similar lines, so that a description of the various operations is hardly necessary. Attention might be drawn to the numerous details of platinum mining by dredges and other means on the Ural fields of Russia in the monograph by Duparc and Tikonowitch (*see under Bibliography*) which is the latest and most comprehensive work on the subject. There is one method of mining, however, which is only carried on in the platinum industry, although it would be applicable to the working of any alluvial deposits if they happen to be situated in ice-bound areas. The Ural deposits, in part, are in very loose and watery ground and troublesome to exploit, but the miners take advantage of the extreme cold of the region by allowing the workings to freeze, and then operating on the frozen ground by thawing it with wood fires. If the face of the wash in the workings becomes frozen to a depth of, say, 1 ft., then the thawing or burning out will extend for about 6 in. or to a safe limit, the workings then being allowed to freeze again to the maximum depth and the thawing repeated. The operation is simple, but experience is required in deciding how

far to proceed with the burning out, otherwise the ground collapses and the workings become flooded, and another start has to be made.

In the Urals the amount of platinum in the wash is extremely variable, the average yields for one period of years being over 1 oz. to the ton of washdirt. Other years' yields have shown about half this average, while latterly the returns have not been more than  $1\frac{1}{2}$  dwt. to the ton. The thickness of the wash varies from less than 1 ft. to several feet, and 3 or 4 ft. has been estimated as a general average thickness throughout the platinum-bearing country. The extent of this productive area is said to be about 170 square miles, and between 15,000 and 20,000 miners were employed on it before the war.

At Colombia the mining operations in the past have been very irregularly carried on, but are now being conducted systematically with up-to-date appliances, the platinum wash being treated by dredges.

A sample from the Sumatra bornite-garnet-wollastonite-limestone deposits made up of partly decomposed wollastonite yielded on assay 0.17 oz. of platinum and 0.11 oz. of gold per ton, and it was observed that where the copper values in the ores were lowest the platinum values were highest.

At Westphalia, in Germany, the ores contain from 12 dwt. to 1 oz. 4 dwt. of platinum per ton, and are therefore rich compared to the Ural deposits, the payable minimum being considered to be 8 gr. of platinum to the ton. At Sierra del Ronda, in Spain, about 8 gr. per ton has been obtained, which is deemed sufficiently encouraging to warrant further extensive prospecting operations being undertaken.

At Broken Hill, New South Wales, the platinum values in the lode vary from a trace to 16 dwt. to the ton, a felspathic ochre containing about  $1\frac{1}{2}$  oz., and a ferruginous claystone about  $6\frac{1}{2}$  dwt. per ton, palladium and iridium also being present with the platinum. Picked specimens of the ore were also found to contain from less than 1 per cent. up to 10 per cent. of copper, from 0.35 to 4.33 per cent. of nickel and from traces up to 0.27 per cent. of cobalt (Mingaye). At Fifield the alluvial deposits have yielded 6 dwt. 2 gr. of platinum and 1 dwt. 23 gr. of gold to the ton, but there does not appear to be much promise of a continuation of these returns on account of the limited extent of the wash-dirt in the lead. Notwithstanding which, 400 loads recently obtained from ten claims averaged a yield of 4 dwt. of platinum and  $\frac{1}{4}$  oz. of gold.

The ore of the copper mine at Platina, near Walhalla, in Victoria, contains from 2 dwt. 18 gr. to 7 dwt. 20 gr. of platinum per ton, some bulk samples showing from 2 to 7 dwt. of platinum, with gold, silver, and copper also present. (Bayley.) Bores put down at this mine have shown that platinum occurs in the hornblendic lode, and there appears to be no doubt about the metal impregnating a large formation. Assays have shown the stone to contain 4 per cent. of copper, 4 dwt. of platinum, and 2 dwt. of gold to the ton. Prospecting operations were satisfactory, but the ore is only suitable for smelting, and some trouble has been experienced in obtaining a flux for it sufficiently cheap and suitable. Palladium is stated to be also present.

The Sudbury copper-nickel ore treated in past years probably contained 0.01 oz. of platinum, 0.01 oz. of gold, and 0.2 oz. of silver per ton, while the ore now proved to exist in borehole tests show, on assay, 0.007 oz. of platinum, 0.022 oz. of gold, and 0.22 oz. of silver per ton, besides values in nickel and copper. In the matte produced from the ore, during a three-year period, the values average 0.1 oz. of platinum, 0.15 oz. of palladium, 0.05 oz. of gold, and 1.75 oz. of silver pre ton.

The plumbojarasite at the Boss Mine in Nevada when very pure is reported to contain 234 oz. of gold, 15 oz. of platinum, and 64 oz. of palladium to the ton, with high percentages of iron, lead, and bismuth, and that assays have been made showing even higher returns. An average sample of 3 ft. of copper ore in a siliceous gangue from this mine yielded 0.4 oz. of platinum metals, 0.13 oz. of gold, and 1.2 oz. of silver per ton, with 15.1 per cent. of copper.

At Beaume, in Ontario, the chromite occurring in the serpentine contains 13.44 per cent. of chromic oxide and 14.58 per cent. of iron oxide, with 0.073 oz. of platinum to the ton, and the pyrrhotite found at Griqualand, in South Africa, contains from 1.5 to 20 per cent. of copper, with an average of 4 per cent.; 1.5 to 10 per cent. of nickel, with an average of 4 per cent.; and from 2 to 3 dwt. of platinum per ton.

The beach sands of the New South Wales coast vary considerably in their platinum contents, and no definite yield per ton appears to be known, although the value of the concentrates has been determined. The yields of gold, platinum, osmiridium, &c., from concentrates obtained at Ballina, Richmond River and Evan's Head are given in Table 44, the results obtained, however, being only from small parcels and not sufficiently general to give any data on which to base a commercial proposition.

TABLE 44.—VALUES IN BEACH-SAND CONCENTRATES, NEW SOUTH WALES.

Locality.	Gold. per ton.	Platinum. per ton.	Osmiridium. per ton.	Other Constituents.
	O. D. G.	O. D. G.	O. D. G.	
Evans Head ..	2 19 3	0 18 17	0 0 15	5.12 per cent. of tin (met.)
Evans Head ..	15 1 12	2 18 3	0 17 7	28.52 per cent. tin (met.)
Richmond River	0 9 11	129 9 16	58 0 7	5 oz. iridium per ton
Ballina .. ..	2 19 12	428 9 4	161 13 20	26 oz. 16 dwt. Ir. per ton and 2 oz. 16dwt. plat. metals.

A sample of the platinum metals on assay was found to contain—Osmiridium 40.82 per cent., platinum 26.12 per cent., iron 27.17 per cent., copper 2.51 per cent., silica 1.33 per cent., total, 97.15. Sample was strongly magnetic.

At Currumbin Beach, near Point Danger, some mining operations have indicated the beach sands to be of small value, and it is evident that the working of the sands in this locality, to be successful, must be conducted with very much more efficient labour-saving appliances than have been employed. The yields occasionally have shown that the sands contain high values in tin, gold, silver, platinum, and monazite—that is, from 8s. to 12s. per ton; but the general averages must be put down to about as many pence per ton, and even then the platinum values are exceeding small in comparison with those of the other constituents. The values obtained from a number of tests are given in Table 45.

The sands on the Pacific coast of California and Oregon contain appreciable quantities of platinum in an exceedingly fine condition, but with the difficulty of treatment no proposition has been advanced to economically save it.

In concentrating platinum-bearing sands one method consists in producing a rough concentrate by jigging, and then a high concentrate by treatment on a wilfrey or other shaking table, the concentrate then being in a form suitable for metallurgical refining by one of the processes mentioned further on under Metallurgical Notes.

An experiment tried with a sample of Currumbin sand showed the black grains to be much finer than the white siliceous portion, and that by passing the sand over an 80-mesh sieve a fine black concentrate was obtained which only contained about 30 per cent. of white sand. The black sand was also found to be highly magnetic and a high percentage of the fine-screened concentrate could be removed by this means, the operations of screening and magnetic separation together yielding a product which probably would be no more than 5 per cent. of the original bulk. Such fabrics as cocoanut matting, blankets, "onion bagging," and carpet in the bottom of the sluice boxes usually

employed in beach mining are very troublesome to keep in order, and to be effective require careful attention, so that in the utilisation of metal screens, magnetic separators, and jigs, with other labour-saving mechanical arrangements, a possibility exists

TABLE 45.—VALUE IN BEACH SANDS, CURRUMBIN, QUEENSLAND.

Locality.	Tin.	Gold. Per Ton.	Silver. Per Ton.	Platinum Per Ton.	Thickness of Bed.
	%	O. D. G.	O. D. G.		
Flat Rock ( $\frac{1}{2}$ mile S.E. of) ..	0.18	0 0 12	0 4 2	trace	18 inches
Flat Rock (1 mile S.E. of) ..	0.17	0 1 19	0 3 22	trace	4 feet
Flat Rock ( $1\frac{1}{2}$ miles S.E. of) ..	trace	0 1 0	0 4 10	trace	6 inches
Coolangatta Cr. (50 chs. N.W. of) ..	0.64	0 0 17	0 4 20	trace	6 inches
Flat Rock Cr. (mouth of) ..	0.26	0 1 7	0 7 2	trace	4 feet
Flat Rock ( $2\frac{1}{2}$ chs. S. of) ..	trace	0 0 5	0 3 22	trace	3 feet
Flat Rock ( $2\frac{1}{2}$ chs. S. of) ..	0.12	trace	0 3 12	trace	18 inches
Flat Rock (3 chs. S.E. of) ..	trace	0 0 5	0 4 22	trace	4 feet
Concentrates* ..	8.30	1 16 8	0 12 19	trace	
Concentrates† ..	1.69	0 7 5	0 5 5	trace	
Concentrates‡ ..	0.10	0 0 22	0 5 3	trace	

\* Results of 2 weeks' sluicing, 191 lb.

† One week's work, 3 cwt. of high-grade concentrate from 20 tons of sand.

‡ Results of 20 tons of sand, 7 cwt. of low-grade concentrate.

of effectively handling the black sands on this part of the coast. Capital appears to have been spent in attempting the recovery of the metals on the New South Wales coast, but opinions differ as to whether the cause of the failures has been through the poorness of the sands, mechanical difficulties, or bad management.

### Prospecting for Platinum Metals.

Prospecting for the platinum group of metals in lodes may present many difficulties on account of the trouble in identifying them when in association with other minerals. Rich deposits of native metals, such as platinum and osmiridium, can be easily recognised by the experienced prospector, while other deposits containing platinum in complex ores might be passed over without the presence of the platinum being suspected.

Perhaps the first thing to do would be to acquire sufficient mineralogical knowledge to be able to identify the minerals with which platinum or its allied metals are known to be associated, and another important desideratum would be the ability to identify the kind or classes of country in which the platinum minerals would be expected to occur. The descriptions of "Minerals containing Platinum," given on page 128, and the "Geological Features" concerning platinum deposits, page 132, will be of some assistance to an understanding of the subject, although experience would be necessary before a prospector could be considered well qualified for the work.

Probably the best course to adopt in a prospecting expedition would be to include in the party one with a knowledge of rocks and petrological work, and who would be able to detect and

estimate native platinum in samples of ores not too complex, and in addition to include a number of miners experienced in prospecting for alluvial deposits, such as in following up indications in creeks and gullies and taking dish prospects from "wash" appearing favourable for the occurrence of heavy minerals.

In Queensland many localities are known which should be prospected for platinum, more particularly those about Cawarral, Canoona, and Marlborough, near the coast to the north and north-east of Rockhampton, where an enormous area of serpentine exists. This belt is known to be auriferous from almost one end to the other, and also to contain several chromite deposits. The geological conditions, however, are those laid down for the occurrence of platinum, and if the latter metal were proved to be absent it would show, at least, that the "indications" of its occurrence are not always to be depended upon. Large chromite deposits are known near Tungamull, on the Cawarral field, and near Glen Geddes, midway between Rockhampton and Marlborough, but other unimportant deposits are also known, while numerous diorite outcrops are to be observed about Marlborough, Princhester, Canoona, and Kunwarara and other localities traversed by the Rockhampton-Mackay railway line.

It might be mentioned, however, that although the vicinity of chromite deposits appears to be the most favourable for the occurrence of platinum, experience has indicated that some rocks poor in chromite have higher values in platinum than those rich in chromite.

The serpentines at Kilkivan, Marodian, and Black Snake to the west-north-west of Gympie, are mineral-bearing in many places, with gold, copper, nickel, cobalt and manganese also present in some of the lodes. Fat Hen and Angella Creeks, where platinum has recently been reported to occur, are in serpentine and schist country, the former creek heading in an area of country containing copper, nickel, cobalt, and gold.

The serpentine areas at Kandanga to the south-west of Gympie are probably a continuation of the serpentine at Black Snake to the north-west, but so far no chromite deposits are reported to occur in them, although large lodes of manganese are quite common in the slates adjacent.

Close to the port of Bowen at Mount Pring an area of serpentine was discovered a few years ago, and the preliminary examination then made indicated the presence of chromite in the gravels of the water courses, and the conditions which prevail there are ideal for the concentration of alluvial platinum from decomposed serpentine.

Near Pine Mountain close to Ipswich, and Mount Crosby near the Brisbane River there are areas of serpentine country which contain small irregular deposits of chromite and magnetite, and in which peridotite dykes have been observed. The areas are small but should receive attention.

The Peak Downs Copper Mine at Copperfield near Clermont which yielded such phenomenal returns many years ago contains a series of mineral lenses separated by serpentinous schist formations. The possibilities of platinum occurring with the gold in the copper ores has not been considered, although chromite boulders have been observed along the pronounced lode outcrop, which extends for many miles. The serpentine trends southerly from this locality and makes its appearance below the alluvial deposits at the Anakie Sapphire Fields.

Serpentines occur in North Queensland at Herberton, Koorboora and Watsonville in an important area of mineral-bearing country, and also at the Calliope and Mount Rainbow goldfields in the Gladstone district, their occurrence also being recorded at Mundubbera near Gayndah where they form a belt in slate country.

The old Hector Mine close to Rockhampton contains a slightly nickel-bearing pyrrhotite with copper pyrites and iron pyrites in a hornblende rock closely associated with a gold-bearing quartz lode. The gold was the only mineral saved, and no attention was given to the other content of the ore.

The copper deposits at Mount Chalmers and Warminster at Cawarral are on or near the junction of serpentine and slate country. Serpentine outcrop close to Warminster and a serpentinous slate is associated with the copper sulphides and oxides in the mine there, and in both localities the slates are much impregnated with barytes. Altogether, the conditions which prevail are indicative of the presence of platinum with the gold and copper in this neighbourhood.

The wollastonite type of mineral deposit is represented at the Mount Hector copper mine near Many Peaks in the Gladstone District, in which the copper occurs as bornite in the wollastonite, with limestone, garnet rock, and granite as the associated country rocks, with serpentine in the district. Probably no thought has been given to the occurrence of platinum, but the conditions here are similar to those prevailing where wollastonite has yielded platinum.

The coastal beaches should also be examined in the vicinity of rivers draining serpentine areas. As stated previously the northern side of the entrances of the streams are favourable for

the accumulation of minerals associated with platinum, because the northern trend of the ocean currents close to the shore results in the sands drifting in that direction. Further, it should be noticed whether beds or seams of black sand occur in any locality before any operations are undertaken, as without such deposits being present platinum could not be expected to occur. The black sand accumulates on the beaches only during rough weather, when small clean bands of it are formed on the surface of the siliceous sands and sometimes quite free from other mineral. The platinum and other heavy minerals in the black sand are exceedingly fine and the question has been raised whether the platinum grains, in being the finest of all the assortment of minerals, would gravitate in time into the coarser and more open sands below or remain in the bands of fine black sand.

Currumbin Beach near Point Danger has been the site of several prospecting operations for gold, and in places the sands there have been found payable to wash in sluice boxes, but platinum and osmiridium have only been found in traces. Further north along the beaches the quantity of these minerals present becomes less and less, although the black sand accumulations are just as persistent. To the south of Point Danger on the New South Wales coast the platinum values in the sands would no doubt be greatest near the outlet of the rivers which drain the serpentine area.

The coastal beaches north of the Fitzroy River near Rockhampton should also be examined, although the prospects would not be very favourable on account of this river draining an enormous area of country, of which the serpentines are only a very small portion. Palm Creek and other watercourses in the vicinity of Cawarral and Herbert's Creek further north head in country containing serpentine, and possibly good results would be obtained by an examination of the black sand accumulations where these and other small creeks enter the ocean.

Finally it must be remembered that coastal black sand deposits might form from the disintegration of many kinds of rocks and may contain no chromite, and if so would probably not contain platinum or osmiridium, so that the first test to be applied would be to determine the presence of this platinum and osmiridium indicator. It might also be mentioned that there are numerous carbonaceous black sand deposits on many parts of the coast and on some of the islands, but these could not be mistaken for the black sands containing the heavy minerals.

### Metallurgical and Chemical Notes.

*Properties of Platinum Group Metals.*—Pure platinum is tin-white in colour, has a specific gravity of 21.5, a hardness of 4 or 5, and is very malleable—although less so than gold and silver. Its fusing point is,  $1,750^{\circ}$  C., which is nearly twice as high as that of silver. It expands less on heating than any other metallic element, but has the same expansion as some nickel steels, which in consequence are sometimes used as a substitute for it. It is not acted upon by nitric, sulphuric or hydrochloric acid, but is soluble in nitro-hydrochloric acid—one to two parts respectively. It is corroded by sulphides, sulphates, phosphates, and arsenides, more particularly those of easily fusible metals such as lead, bismuth, tin, mercury, antimony and zinc, if heated in contact with them, and is also affected by various other inorganic and organic compounds. Unlike gold and silver, it will not amalgamate with mercury unless sodium or some special reagent is present, and if the former be washed out with water from a platinum amalgam containing it the platinum itself becomes disassociated from the mercury. Platinum resists oxidation even at high temperatures, and thus becomes a useful metal in chemical and electrical work.

Palladium is a silver-white metal, as hard as platinum, although not so ductile. Specific gravity, 11.97. When heated first becomes blue, and then silver white at higher temperatures, but is infusible. More easily acted upon by acids than any other platinum group metal, but has better catalytic properties than platinum. At normal temperatures will not tarnish, but will oxidize on the surface when heated.

Osmium is a bluish-white metal somewhat like platinum. Specific gravity, 22.477. Infusible, but easily oxidised and at a high temperature volatilizes. More closely related to ruthenium than platinum.

Iridium is a white metal as bright as steel. Specific gravity, 16.19. Not attacked by acids. Forms a fusible alloy with platinum.

Ruthenium is a lustrous white hard metal. Specific gravity, 12.06. Has catalytic property when finely divided, and is superficially oxidised at a bright red heat.

Rhodium is a white hard malleable metal. Specific gravity, 12.1. Has catalytic property, and is characterised by rose red salts.

*Reduction of Platinum Ores.*—The platinum in the impure native alloys is first converted into lead-platinum alloys by a furnace fusion with galena (lead sulphide) on a clay hearth,

the sulphur combining with any iron present in the ore to form a regulus. Osmiridium if present will not alloy with the lead, and settles to the bottom of the charge, being heavier than the alloy. The removal of the iron and sulphur from the platinum-lead is effected by first introducing ground glass to make a slag and to absorb the iron, and then litharge (lead oxide) is added to remove the sulphur, after which the platinum-lead is cupelled to drive off the lead, a residue remaining which contains all the platinum and perhaps palladium, rhodium, osmium, and iridium.

In treating platinum-bearing ores, one English firm advertised before the war that it would undertake the work, charging £60 per ton for the treatment, and buying the metal at market prices. In refining scrap or crude platinum the charge is about 30s. per oz., but the cost of doing so is stated to be only about 30s. per lb.

*Refining Platinum.*—The crude platinum obtained by cupellation is sometimes fused with lead and then granulated and afterwards treated with weak nitro-hydrochloric acid. It is also treated direct with this acid to dissolve any gold which might be present, and then with strong acid to dissolve the platinum, a residue of iridium being left behind if this metal is also present. The platinum in the solution is precipitated as a chloride, this compound then being decomposed by heating to redness to form spongy metallic platinum.

*Wollaston Platinum Process.*—The treatment of crude platinum requires to provide for the separation of platinum, palladium, osmium, iridium, rhodium, and ruthenium, and also gold, silver, iron, and copper. In the Wollaston process the gold and silver is first removed by amalgamation, and the solution of platinum chloride, as made above, is precipitated with ammonium chloride to form a double chloride of platinum and ammonia. The double chloride is heated to redness to produce spongy platinum, which is then pressed into discs about  $2\frac{1}{2}$  in. in diameter and heated to whiteness, and then welded into a solid mass. When palladium or any other metals of the platinum group are present and require to be removed various modifications of this process are necessary.

*Deville and Debray's Oxy-hydrogen Process.*—The refined platinum prepared by the wet process of Wollaston may contain some osmium and silicon, to remove which the metal is fused in the oxy-hydrogen or oxy-coal gas furnace in lime crucibles. This expels the osmium as a gas, and the silicon combines with the lime to form a lime silicate slag. The fused platinum is cast into ingots and then rolled into rods, sheets, and foil, drawn into wire, or hammered into crucibles, dishes or retorts.

*Platinum Sponge.*—The spongy platinum referred to above is in a very porous condition, and in thus possessing a very large surface area compared to its weight and in having the property of condensing oxygen it is employed as an oxidising agent for a large number of purposes.

*Platinum Black.*—This is a finely-divided black metallic powder, produced by precipitation from a solution of a platinum compound such as a weak chloride with a reducing agent, or by treating alloys of platinum and soluble metals, such as copper and zinc, with dilute acids. Its special quality is, like spongy platinum, its power of absorbing or condensing many times its bulk of oxygen, and is exceedingly useful in absorbing this element from the atmosphere and discharging it into various other gaseous compounds, as in the conversion of sulphurous oxide to sulphuric oxide or in the condensation of the vapour of alcohol into acetic acid in the manufacture of vinegar. This action of platinum, which is termed catalytic, enables many chemical changes to be accelerated between substances which otherwise would only take place very slowly, and without any appreciable change taking place in the metal itself during the reactions.

*Palladium Recovery.*—This metal, for the most part, is collected in the matte smelting of the copper-nickel ores of Sudbury in Canada. The process adopted for its recovery is that used at the works of the Mond Nickel Company in England, where the matte is treated first for its copper and nickel, then for its platinum, palladium, gold, and silver.

*Platinum in Copper.*—In electrically refining copper it has been observed that platinum and palladium frequently occur in blister copper, and that these precious metals appear to be derived from the copper ores from which the blister has been made. Such ores have been obtained from Mexico, United States, and Peru, and the estimated platinum contents of the blister made from them has been found to vary from 0.319 to 1.825 oz. per 100 lb., and the palladium contents from 0.226 to 6.486 oz. per 100 lb., while blister copper made from Tasmanian ore yielded 0.624 oz. of platinum and 1.374 oz. of palladium per 100 lb.

An opinion has been expressed that all copper sulphide ores contain at least minute quantities of one or other of the platinum group metals, and that we do not find them in Australian ores because they have not been looked for.

In the Mond volatilisation process for treating the copper-nickel ores of Ontario, by which carbon monoxide is utilised in

separating the nickel from the copper in the form of nickel carbonyl gas, the platinum and palladium are recovered from the residues, but in the International Nickel Company's process for treating the same ores, in which the two metals are alloyed in the smelting operations, most of the platinum metals are absorbed by the nickel-copper alloys, and any recovery is only from specially rich ores separately treated.

*Recovery and Assay of Native Platinum.*—Sands or concentrates containing alluvial platinum can be tested by using as an electrolyte a solution made up by weight of one part of sulphate of copper, one part of sulphuric acid, and 2,000 parts of water, which, with an ounce or two of zinc amalgam (made by alloying mercury with fused zinc to form a liquid) is mixed with a sample and agitated in a bottle or other vessel. Any platinum or gold present will combine with the zinc amalgam, which is then separated from the sand or concentrate by washing in a dish (not tinned) or by passing over an amalgamated copper plate. Alternately, the zinc amalgam can be used on the plate instead of mixing with the sand and the platinum collected on it as the sand is passed over.

The amalgam thus separated in the dish or caught on the plate is squeezed through chamois leather or thick canvas to remove excess of mercury, the portion remaining in the form of a soft ball or pellet of amalgam being retorted and refined for the precious metals which it might contain. This process can be used both for the assay of bulk samples and for the recovery of the platinum on a working scale.

By some it is contended that the zinc is not necessary in the above operations, either for recovery or assay, and that the refining is simplified by the zinc being absent. Others affirm that roasting the ore before amalgamation is advisable, to destroy or remove substances which might interfere with the combination of the precious metals with the mercury.

Sodium amalgam can be used very effectively instead of the metallic zinc and copper sulphate for assaying platinum, although it would be expensive if used for its recovery on a commercial scale. Any gold present with the platinum in a sodium amalgam can be separated from the platinum by washing the amalgam in excess of water, which converts the metallic sodium into an oxide and thereby sets free the platinum grains, the latter not remaining in an amalgam without metallic sodium being present.

The assay and recovery of platinum in lode material in some cases may be carried out by the above methods, but the ore requires to be very clean and uncontaminated by mineral impurities.

The testing of samples for platinum gives very unsatisfactory results unless extreme care is exercised in both the selection of the samples and their treatment afterwards. One experiment quoted by Hill\* showed that two tests of the same sample gave 33 grams and 3 grams respectively, and another one 8 grams and 0.8 grams. Professor Krusch† is of opinion that the unreliable results are due to the irregular distribution of the metal in the ores, notwithstanding its great fineness. He also considers that nothing less than one-ton samples should be taken, and that the whole of the platinum in this quantity of stone should be extracted.

In regard to laboratory practice, Mr. Smoot, Chief Chemist of Ledoux and Co., New York,‡ has published some interesting data on the determination of platinum values, and concerning the assay of silver ores containing platinum metals, and Mr. Martin Schwitter,§ Chief Chemist of Goldsmith Brothers Refinery Co., of Chicago, has given details of the determination of osmiridium, platinum, gold, palladium, and rhodium, in both of which papers there will be found some useful information. It has also been observed that in ordinary gold assaying the presence of platinum in the gold beads formed in the cupelling operations has a tendency to produce an efflorescence or spurting on the surface of the metal at the time of cooling.

“Primary Deposits of Platinum in the Urals,” is the title of an article by A. Enostranzeff, reprinted in “Platinum and Associated Metals” (Kemp). In it is discussed the chemical treatment of ores for the recovery of platinum, and some of the experiments which were carried out showed the necessity of great care in conducting the operations.

In an article on “The Determination of Platinum,” by F. P. Dewey,¶ reference is made to the treatment of the beads of

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\* The Production of Platinum and Allied Metals in 1914. By J. M. Hill, U.S. Min. Res. Pt. 1 (1915), p. 342.

† The Platinum Deposits of Germany's Palaeozoic. Min. and Sci. Press. Vol. 109. Dec. 5 (1914), pp. 879-881.

‡ Determination of Platinum, Palladium, and Gold. By A. M. Smoot, Eng. and Min. Jour. Ap. 17. (Vol. 99) 1915, pp. 700-01; and reproduced in the U.S. Geol. Survey Min. Resources for 1914, pt. 1, in the article by J. M. Hill on the Production of Platinum and Allied Metals in 1914.

§ The assay of Crude Platinum. By Martin Schwitter. Eng. and Min. Jour. June 20 (Vol. 97) 1914, pp. 1249-1250. Reprinted in U.S. Geol. Surv. Min. Res. for 1914, pt. 1, in the article by J. M. Hill.

¶ Eng. and Min. Journal, October 14th, 1905, p. 679.

metal produced by fire assay of platinum-bearing ores, and the author offers some useful suggestions for the elimination of errors.

A review of all the methods of platinum analyses is given by Duparc and Tikonowitch\* and details are furnished concerning the methods of Berzelius, Claus, Deville, Debray, Stas and Leidie, together with notes on the separation of osmium, ruthenium, and other platinum metals.

Mr. A. W. Dye, assayer, of Sydney, in a personal communication on the subject of platinum assaying, states that "The difficulty experienced in obtaining reliable results in platinum assaying is largely due to cupellation of the material with too little silver, and much too little heat at the finishing stages of the operation. A second difficulty is that silver is not soluble in sulphuric acid unless the latter is absolutely boiling, and many assayers mistake the ebullition of whitish gas bubbles as an indication of a boiling temperature, but this is not the case. When the liquor actually boils, and the action on the silver is complete, no trace of the "seething" is apparent, but there is simply a lazy bubbling action. The residue after dissolving is insufficiently washed in the majority of faulty assays, with the result that silver is held up in the same way as in gold bullion assays, but with none of the consistency associated with the latter metal. It is for this reason that so many differences occur, and in London it is the practice to weigh this residue and then to dissolve in a minimum quantity of aqua regia. The liquor is then carefully evaporated to dryness to eliminate nitrates, then taken up in hydrochloric acid, and again evaporated to dryness, afterwards being taken up in water and filtered. The gold is then precipitated with oxalic acid or sodium nitrite, and filtered off, cupelled and parted in the usual way. The platinum is then precipitated by the action of pure zinc foil, the liquor being acidified for this purpose. When the solution is quite colourless and free from platinum, the residue is filtered off, ignited to convert traces of zinc to oxide, and boiled in strong hydrochloric acid, afterwards being filtered, washed with boiling water, dried, ignited, and weighed for the determination of the platinum, less such ash as would be present. Platinum assays as obtained by this latter method are in a general sense much lower† than those obtained by the direct weighing (from sulphuric acid) of the gold‡ and

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\* *Le Platine et les Gîtes Platinifères de L'Oural et du Monde.* Geneva, 1920.

† Due largely to the platinum being pure and also being free from group metals.

‡ Platinum group metals.

“platinum” together, and subsequent elimination of the platinum by repeated inquartation and subsequent parting in nitric acid. Standardisation of the heat employed, the weight of silver used in parting, the actual parting by at least two prolonged *boilings* in strong sulphuric acid, and annealing at high temperature to eliminate the last traces of acid, all tend to put even the direct method of assay on a fairly accurate basis. It may be stated that the silver used in such parting rarely exceeds two and a-half times the weight of platinum and gold present, in contradiction to the usual text-book recommendation of ten or more times, and the smaller quantity is quite sufficient if the correct temperature is employed in cupellation. The trouble in obtaining concordant results would appear to be the employment of *various degrees of heat* in cupellation, parting, and annealing instead of at a standard temperature, and also in having *varying lengths of treatment and strengths of acids.*”

### Uses of Platinum.

*Jewellery.*—During recent years the use of platinum in jewellery has been increasing, and just before the war its application in this way appears to have absorbed 1,000,000 oz., or about 18 per cent. of the world's output. The consumption for this purpose is being reduced at the present time, and necessarily so, because the available supply of the metal is limited and other important demands are very great. Possibly the future industrial requirements will be so urgent that some drastic action will be taken by the authorities to considerably limit its use for fashionable adornment.

In the United States the demand for platinum in jewellery required an annual supply of nearly 60,000 oz., but the supply of the metal for munition work was found to be so imperative that the United States Jewellers' Association, in a patriotic spirit, published and distributed all over the States copies of a number of resolutions they had passed pledging the Association to discontinue the use of platinum for all jewellery purposes, recommending all others in the trade to do the same, and asking them to advise all their customers to use gold instead. This recommendation applied more particularly to scarf pin stems, pin tongues, joints, catches, swivels, spring rings, ear backs, and all heavy and bulky parts of jewellery. The United States Government also appealed to women to hold in readiness all their platinum jewellery, as an absolute necessity might have arisen for the supply of more platinum in the making of high explosives.

In England the urgency appeared to be less acute, but the authorities required jewellers to send in a list of all platinum goods in their possession, and stated that the metal must not go into use for jewellery purposes.

Pure platinum is used to a great extent in making fine chains, and crown settings for diamonds, and, while its use for the former should be discontinued, in the latter case there is some hesitation in dispensing with it. No metal setting for diamonds is so artistic as platinum, and the manufacturing jeweller much prefers to work in this metal than in any other. An alloy of 25 per cent. of iridium with platinum is said to be much better than pure platinum for some work, giving greater strength and hardness, and capable of being much more finely chased than gold or any alloy of platinum with another metal. This alloy, however, is not so ductile as pure platinum, and therefore not so desirable in a mounting in which gems have to be reset. A few per cent. of iridium, however, is generally present in jeweller's refined platinum.

The refining of platinum for jewellery and other purposes is now being undertaken by a number of firms in Australia, and Mr. A. W. Dye, of Sydney, is now refining palladium and iridium for trade purposes.

Platinum is used by manufacturers in all degrees of fineness, but in the United States no article is allowed to be marked with the imprint "Platinum" unless the platinum (or platinum metals) is 0.95 fine (95 per cent.). In Switzerland the official stamp for platinum of the same quality is an Alpine goat.

Substitutes for platinum in jewellery work are numerous, and further reference is made to some of them under the heading "Platinum Substitutes."

*Dentistry.*—Considerable quantities of platinum in the form of sheet, wire, foil or amalgam are required in this work, and an estimate has been formed that 1,000,000 oz.—about 15 to 18 per cent. of the world's production—have been utilised in the manufacture of artificial teeth. In the past this metal has been preferred to gold because of its low price, but now that its cost is greater the gold is taking its place.

Platinum alloys for dental work must be very hard and unaffected by organic acids. They generally contain platinum and silver, and sometimes gold or palladium, as shown in Table 46, although they do not compare favourably with pure platinum or pure gold to which a little copper is added to give the necessary hardness. Molybdenum and tungsten are sometimes

used for the rivets or pins of artificial teeth, in which case they are thickly plated or rolled with platinum or with palladium-gold. Molybdenum is also used as a filling in dentists' work.

*Sulphuric Acid Manufacture.*—Platinum is used extensively in processes for making sulphuric acid, for which purpose it must be free from all metallic impurities. In one process the acid is made in towers or chambers and is first concentrated in lead pans, and if a final concentration is necessary to bring it up to the standard of commercial requirements platinum stills are generally installed, further reference to which is given under separate heading.

In making what is called "contact" sulphuric acid, the platinum is used in a fine state, as platinum sponge or as a film covering to a finely divided substance such as asbestos. Sometimes the "contact mass" contains 7 or 8 per cent. of platinum, while occasionally not more than 0.2 per cent. of the metal is present, although very finely distributed over the surface. The success of this process depends on the catalytic property of platinum in a heated condition, reference to which has been made above. The operations consist in burning sulphur or pyrites in a furnace, the sulphurous oxide (anhydride) gas obtained being converted into sulphuric oxide by coming in contact with the heated platinum. This oxide, a crystalline fibrous mass, is then hydrated—that is, changed to sulphuric acid—by mixing with water.

The use of the contact process has enormously increased since 1915 and is specially applied to the making of the highly concentrated acid used in the manufacture of high explosives, the quality of the product being much higher than that made in towers or chambers. The success of the process demanded large supplies of platinum, and to make as much metal available as possible other metals had to be looked for to replace the platinum used in other industries. At the present time 500,000 oz. of platinum are said to be in use in the making of contact acid.

*Platinum Stills.*—These are made of various shapes and sizes, some round, others elongated, and with plain or corrugated bottoms. Gold is sometimes used as a lining, and the life of the stills is thereby much extended. This gold lining is not applied as an electric gilding, but is rolled with the platinum in making the sheets from the ingots. A platinum ingot is heated to nearly fusion temperature, on which is poured molten gold and the double ingot produced is then rolled to make the sheets required.

• The substances most injurious to platinum stills, and to platinum appliances generally, are hydrogen, carbon, sulphur,

silica, mercury, sulphates of iron, lead, alumina, lime and magnesia, and various metals such as antimony, bismuth, arsenic, zinc, lead, copper, gold and silver, which form fusible compounds with platinum and are very destructive.

Substitutes for platinum are now being utilized extensively in making sulphuric acid, and stills made of fused silica or lava, and others lined with tiles are almost entirely replacing platinum for this purpose.

*Manufacture of Acetic Acid.*—One of the processes for making acetic acid is the rapid oxidation of alcohol by either spongy platinum, platinum black, or platinised asbestos. If heated platinum in either of these finely divided forms is in contact with a mixture of air and alcoholic vapour, the formation and condensation of acetic acid and water takes place at once. The process is very effective and gives a pure product, but the first cost of the platinum seems to prevent its being used on an extensive working scale.

*Nitric Acid.*—In the making of this acid the nitrate of soda found in nature is the ingredient from which most of the world's supplies have been obtained, but the supply of this salt is falling short of requirements and a serious demand might be made on platinum to furnish the catalizer required in converting ammonia into nitric acid by a process of oxidation.

*Platinised Asbestos.*—The asbestos used in making this catalyzer has to be very finely fibrous, the operation of platinising being performed by first heating the fibre to remove all moisture, then dipping it into a solution of platino-ammonium chloride, then warming it to dry the chloride coating, and finally igniting it to decompose the salt into finely-divided platinum. Deposited thus on asbestos the platinum is exposed over a large surface area, and compared to the weight of metal used is more effective than either platinum sponge or platinum black. Other substances may be used as bases for the platinum films provided they expose a large surface area and are not fusible, and also if they are not acted upon by acids.

*Chemical Work.*—In the chemical analyses of rocks platinum crucibles are indispensable. The rock constituents require to be brought into a soluble mass, and this necessitates fusions being made in a metallic crucible and the use of fluxes. Gold and silver cannot be used because they will not resist high temperatures, and for various reasons crucibles made of other metals are not suitable. It is only since platinum crucibles were introduced that it has become possible to accurately estimate the

composition of rocks, and an enormous amount of scientific information has been obtained by the use of this simple piece of apparatus. In the form of crucibles, dishes, retorts, stills, &c., the platinum used in chemical operations constitute, it has been estimated, 10 per cent. of the whole world's supply, and it has also been stated that 1,000,000 oz. are being used in general chemical work at the present time, including of course the making of sulphuric acid.

*Electrical Appliances.*—A common use for platinum at one time was the lead-in wires of incandescent lamps and the spark-plug points of internal combustion engines, but now these are made of metallic molybdenum, tungsten, or an alloy of chromium and nickel, all nearly as effective as platinum and much cheaper. If, however, platinum is used it is alloyed with from 15 to 50 per cent. of iridium. Silver-palladium is also used in spark plugs, one of the alloys which contain 60 per cent. of silver and 40 per cent. of palladium being the best for resisting spark erosion, while another containing 95 per cent. of silver and 5 per cent. of palladium is used where the points are exposed to sulphur fumes.

Platinum anodes are used in the electrolytic determination of metal percentages, and the Smee battery cell is made, in part, of a plate of silver coated with platinum, while platinum alloys are utilized to a great extent in telegraph and telephone instruments and apparatus. In electrical furnace work the resistance wires were once usually made of platinum, but this metal is now being substituted by molybdenum both for this and other electrical purposes. Nevertheless, the quantities of platinum used in the numerous electrical meters, appliances and devices are very great, and it is said that 250,000 oz. are now being applied in various ways.

*Pyrometers.*—The construction of these instruments for measuring high temperatures in furnaces vary much in detail, some pyrometers being based on optical principles, others on the thermal or electrical properties of metals or other substances. The pyrometer of Le Chatelier is made of a thermo-electrical couple consisting of wires of platinum with an alloy made up of 10 per cent. rhodium and 90 per cent. platinum, while the pyrometer of Sieman is in part constructed of a coil of platinum wire. Two other combinations for thermo-electrical couples are pure platinum combined with platinum-rhodium alloy and with platinum-iridium alloy.

*Platinotype Photographs.*—When photographic paper is sensitised with a solution of ferric oxalate mixed with potassium

platino-chloride and exposed to light, the ferric oxalate is reduced to the ferrous form and the platinum salt to metallic platinum, the ferrous oxalate on treatment with a solution of potassium oxalate then being totally dissolved. Where the sensitised paper is exposed to light under a negative the platinum is reduced to metal and becomes fixed on the paper, but where the light cannot penetrate there is no reduction of the ferric salt to the ferrous condition and the platinum salt remains soluble and is washed out of the paper with water. There are other modifications of this process, all based on the reactions of ferric and ferrous oxalate, potassium oxalate, and potassium-platinum chloride.

*X-Ray Photography.*—Barium platino-cyanide has the property of becoming fluorescent, and converts the X-rays and the ultra-violet light rays into visible radiations. This platinum compound is applied as a coating to a projecting screen, on which the shadows made by the rays are outlined.

Platinoid, a white metal alloy resembling German silver, is used in electrical work, but does not contain any platinum, and "platinum lead," or "Birmingham platinum," is made up exclusively of zinc and copper.

*Platinum Metal Alloys.*—Platinum alloyed with from 5 to 10 per cent. of gold gives a very elastic metal, but this quality disappears if the amount of gold present is any greater, while with 20 per cent. of gold the alloy is quite brittle. Very small quantities of platinum alloyed with silver produce a hard and tough metal, but if in excess cause brittleness. It is also found that, in a general way, the addition of platinum raises the melting point of silver but lowers its thermal conductivity.

Rhotanium, a white alloy, contains from 60 to 90 per cent. of gold and from 10 to 40 per cent. of palladium. It has a specific gravity of 16.0 to 18.5, is malleable, ductile, and can be welded without fluxes. In chemical and electrical work it would be very useful, but cannot be used with hot concentrated nitric acid, neither can it be used for electrolytic anodes. In jewellery it might be useful, as it is said to be harder and stronger than platinum, will take a better finish than that metal, has very much the same colour, can be worked easily and will not corrode or tarnish.

Platinum alloys of a golden colour have been used in jewellery, some of which are much more durable than gold. The composition of a few are given in Table 46. In making these alloys the metals must be pure, and iron particularly must be absent, 1 per cent. of this metal making the alloys brittle and unworkable. The more fusible metals are melted first, and the platinum, preferably in the form of "platinum black," is added

when the other constituents have been brought to the greatest possible heat. Platinum also alloys with lead, bismuth, zinc, and antimony with which it forms a series of more or less fusible alloys.

TABLE 46.—COMPOSITION OF PLATINUM AND OTHER ALLOYS.

Alloys.	Pt.	Cu.	Ag.	Au.	Ni.	Pd.	Other Constituents, &c.
	parts.	parts.	parts.	parts.	parts.	parts.	
Electrician Alloy	..	..	3	..	..	2	For spark plugs
Jewellery Alloys—							
Platinum Alloy	1	0-1‡	2-5§	..	..	..	White alloy
Platinor ..	2	5	1	..	1	..	Brass, 2
Palladium Alloy	..	..	..	..	..	9	Rhodium, 1
Palladium Alloy	..	..	14	..	..	5	Cobalt, 1 : white alloy
Mock Gold ..	7	16	..	..	..	..	Zinc, 1
Mock Gold ..	1	..	1	..	6	..	Brass, 1
Mock Gold ..	1	4	..	..	..	..	18-carat gold colour
Cooper's Pen Metal	4	1	3	..	..	..	Once used for tipping pens
Watch Alloy ..	..	13	11	18	..	6	Non-magnetic, brownish
Watch Alloy ..	..	25	4	..	1	70	red, hard, malleable
Watch Alloy ..	63	18	..	..	17	..	Cadmium, 1
Platinum Bronze	1	..	..	..	90	..	Tin, 9 : proportions vary
Dentists' Alloy*	5	..	..	3	..	4	White hard metal
Dentists' Alloy ..	7	..	3	2	..	..	White hard metal
Dentists' Alloy ..	6	..	1	2	..	..	White hard metal
Dentists' Alloy ..	..	..	..	4	..	1	White hard metal¶
Dentists' Alloy ..	..	..	2	..	..	3	Also for electrical work

\* Copper sometimes added to increase the hardness.

‡ The amount depends on hardness required.

§ Varying with the quality required.

¶ Also for jewellers' work.

*Other Uses.*—These include its application as a constituent of a non-magnetic alloy substitute for steel in watches, the making of permanent colours in pottery, its use in chronometer and theodolite parts, standard assay and chemical weights, self-lighting lamps, igniters, Davy glow lamps, Russian coinage, parts of apparatus used in physical laboratories to illustrate the properties of light, heat, electricity and radio activity, and as a catalizer in the oxidising of oils to fats in the manufacture of soap. It also makes a very beautiful permanent chocolate bronzing for metals, although its cost precludes its use for this purpose. (See page 165 for note on industrial absorption of platinum.)

*Platinum Substitutes.*—The high price of platinum resulting from the increased demand has encouraged the use of a number of substitutes, some of which are quite as effective as the platinum itself. The alloy of 3 parts of palladium with 2 parts of silver (Table 46) is used for electrical purposes, a reference to which and other substitutes is made under "Electrical Appliances." Both gold and silver alloyed with palladium make fair substitutes for the soft platinum used in jewellery work, and molybdenum has also been recommended as a good platinum substitute on account of its silvery-white colour, and because it is softer than steel, is malleable, and will not tarnish, but it is doubtful if any mixed metal is so desirable as the platinum

unalloyed. If a hard metal is required, as in dental work, these alloys of palladium are not suitable. Palau is the name of a gold-palladium alloy recently put on the market as a substitute for platinum in crucibles, and is said to be suitable for many laboratory purposes. A useful platinum substitute in the making of fine chains and other jewellers' work contains 42 per cent. of gold, 54 per cent. of silver, and 4 per cent. of copper.

Iridium with platinum is a commonly used alloy, but 6 to 10 per cent. of osmium is said to be as good as 15 to 25 per cent. of iridium in producing a hard acid-resisting alloy.

A German jewellery substitute for platinum is 90 per cent. of palladium and 10 per cent. of rhodium, which is less costly than platinum and lighter in weight. The German authorities have demanded platinum for industrial purposes, and hence the necessity of making a substitute.

Filaments for electric lamps are now made with a nickel-steel base, first plated with copper and then plated again with platinum, this combination being found to answer as well as an all-platinum filament.

In making stills for concentrating sulphuric acid and for other chemical uses, a suggested substitute for platinum is an alloy of palladium and gold, another effective substitute for pans and stills being the fused silica made in the electric furnace.

"Stellite," the cobalt-chromium alloy with a small addition of molybdenum (see page 111) has been suggested as a platinum substitute for some purposes because it can be made very tough and hard.

*Osmiridium Uses.*—An important use for osmiridium is in the hardening of the platinum required in dental work and in crucibles for chemical work, the iridium contents specially being desired for this purpose, while another application is in the hardening of the tips of gold pens. In utilising the metal for the latter purpose, for which special shapes and sizes are selected, one small piece is soldered to the two tips and afterwards cut in two with a diamond disc saw, the points then being shaped and polished. Platinum tips are also put on to gold pens but they do not appear to answer as well.

The osmium in the osmiridium can be driven off as a gas from the iridium at high temperatures, and the latter can then be alloyed with phosphorus to make phospho-iridium, an alloy which is much harder than osmiridium, and which can be further alloyed in all proportions with platinum, silver, nickel, and iron to make a white metal.

*Palladium Uses.*—Before the war there was no use for this metal because platinum could then be produced much cheaper and is preferred to it for many purposes, but with the prevailing high cost of the latter, the palladium is now being used to some extent as a substitute for that metal, as shown on page 159. Table 46 also shows the composition of some gold-coloured palladium alloys used in the manufacture of watch cases. The principal objection to its use is its liability to tarnish when being heated in the course of its manufacture into articles and appliances, and no doubt as soon as platinum prices become lower its use to some extent in jewellers', dentists', and electricians' work will be discontinued.

*Osmium Uses.*—Principally for hardening platinum, but used in some electric light filaments.

*Iridium Uses.*—Generally alloyed with platinum for electrical and jewellery purposes. Used as tips to gold and stylographic pens.

*Rhodium Uses.*—Principally for thermo-couples in electric pyrometers. Also used for crucibles in chemical work.

### Production and Values.

The figures given in Table 47 show the position of the various countries concerned in the platinum production. Russia appears to have produced 6,663,583 oz. out of the total world's production of 6,989,752 oz., which represents over 95 per cent. of the whole output.\*

The Columbian total production is next to that of Russia in importance, while the production of the United States is also very large. The production of the United States, however, is principally from foreign ores imported for refinery or metallurgical treatment, and very little comes from local mines. The domestic production of the United States includes 570 oz. in the year 1914, 742 oz. in 1915, 750 oz. in 1916, and 605 oz. in 1917.

Within the Commonwealth the yield of platinum in New South Wales is fairly constant, although the quantities are small, but none of the other States are producing the metal at the present time.

The palladium production of the world, shown in Table 47, is limited to the yields from Canada and the United States. The amounts credited to each, however, are subject to some modifications as portion of the metal shown as a United States output no doubt has been obtained from Canadian ores, and there is a probability that the figures showing the yields overlap one another.

\* A later estimate by Prof. Howe (Min. Resources U.S., 1917) gives a minimum of 8,000,000 ounces.

The iridium statistics given in Table 47 appear to show that the whole of the iridium is the production of the United States, but unquestionably some of this is obtained from other than domestic ores.

Osmiridium statistics indicate that Tasmania has produced the bulk of the world's output of this metal, the United States also yielding it in small quantities.

TABLE 47.—TOTAL PLATINUM METALS PRODUCTION BY COUNTRIES UP TO 1918 (in part.)\*

Country.	Years.	Production Ozs. Troy.	Value £	Value per Oz. £ s. d.
PLATINUM.				
Russia .. .. .	1825—1889	1,818,693	No value given	..
	1890—1917	4,844,890	†20,812,561	4 5 11
Colombia § .. ..	1896—1918	214,516		..
United States ¶ ..	1880—1918	144,392	2,609,571	18 1 8
Canada .. .. .	1887—1918	**	30,112	..
	1907—1918	††5,749	†77,192	13 8 6
Borneo and Sumatra ..	1909—1913	900	..	..
New South Wales ..	1894—1918	14,680	44,584	3 0 9
Victoria .. .. .	1911—1913	311*	1,671	5 7 5
PALLADIUM.				
Canada .. .. .	1902—1913	§§14,931	†74,578	4 19 10
United States .. ..	1914—1918	15,504	‡308,533	19 18 0
IRIDIUM.				
United States .. ..	1914—1918	1,383	‡31,547	22 16 2
OSMIRIDIUM.				
Tasmania .. .. .	1910—1918	5,859	83,463	14 4 10
United States .. ..	1914—1918	2,237	‡38,565	17 4 9

\* Statistics obtained from various sources.

† Estimated, in part.

‡ Estimated.

§ Production for 1878 and 1900—1908 not reported.

|| Values not given; very incomplete.

¶ Years 1913—1916 include platinum and allied metals refined from imported crude and domestic matte and bullion.

\*\* Only a few years' production recorded.

†† Recovered from nickel-copper-matte, mostly from Canadian ores.

§§ Of this amount, 4,461 oz. were recovered at the Nickel Company's Works, New Jersey.

The world's annual production some years ago was about 300,000 oz., but in the year 1913, just before the war, the yield was 217,284 oz., while in 1914 there was an increase to 265,308 oz. Then a steady decline took place up to 1917, the last year for which complete records are available, when the production was 115,315 oz.

The Russian statistics show a very large decrease in the returns of platinum during the years of the war, as shown in Table 49, and it is difficult to form an opinion as to whether the decreased production has resulted from the unsettled conditions in the country causing mining stagnation, or whether there has been a failure to obtain official returns of the yields of such mining as has been undertaken, and a failure in preventing the platinum which has been won from being surreptitiously taken out of the country.

Table 48 shows the world's production for a number of years, and also the gradually diminishing yields of Russia.

TABLE 48.—PERCENTAGE OF RUSSIAN TO THE WORLD'S PLATINUM PRODUCTION.

—						World's.	Russian.	
						ozs.	ozs.	percentage.
1913	..	..	..	..	..	217,284	200,406	92.23
1914	..	..	..	..	..	265,308	241,200	90.91
1915	..	..	..	..	..	151,744	124,000	81.71
1916	..	..	..	..	..	139,693	86,508	61.92
1917	..	..	..	..	..	115,325	50,000	43.35

The Colombian returns in Table 49 indicate that the production is increasing, and about doubles itself every four-year period. In the United States the recovery of platinum in the metallurgical refineries shows remarkable results, and in 1918 the increase in the yield was fifteen and a-half times that of 1914 at the beginning of the war.

TABLE 49.—ANNUAL PRODUCTION OF PLATINUM METALS BY COUNTRIES  
1913-1918 (IN PART).

Country.	YEARS.					
	1913.	1914.	1915.	1916.	1917.	1918.
PLATINUM.						
Russia ... .. *oz. Troy	200,406	241,200	124,000	86,508	†50,000	...
Value £	1,525,500	1,909,300	931,500	1,185,200	837,500	...
Colombia ... †oz. Troy	15,000	17,500	19,000	25,000	32,000	35,000
United States ... ‡oz. Troy	1,034	3,430	6,495	24,518	33,009	54,000
Value £	9,694	32,156	67,156	426,000	707,080	1,200,640
**oz. Troy	483	570	742	750	605	...
Value £	4,500	5,400	7,700	13,000	13,000	...
Canada ... .. †oz. Troy	300	700	250	500	500	300
†Value £	2,800	6,600	2,500	8,700	10,700	6,600
Borneo and Su- matra ... .. oz. Troy	200	...	...	...	...	...
Burma ... .. oz. Troy	58	...	18	...	...	...
New South Wales oz. Troy	442	244	56	82	259	607
Value £	3,135	2,129	476	687	2,072	7,075
Victoria ... .. oz. Troy	127	...	...	...	...	...
Value £	682	...	...	...	...	...
PALLADIUM.						
Canada ... .. oz. Troy	300	700	250	500	500	300
†Value £	2,800	6,600	2,500	8,700	10,700	6,600
United States ... oz. Troy	...	2,635	1,541	2,885	4,779	4,024
†Value £	...	24,400	17,700	49,300	103,200	114,012
IRIDIUM.						
United States ... ‡oz. Troy	...	64	274	370	210	465
†Value £	...	600	3,200	6,300	4,500	16,953
OSMIRIDIUM.						
Tasmania ... .. oz. Troy	1,262	1,019	247	222	332	1,609§
Value £	12,016	10,076	1,581	1,899	4,898	44,833
United States ... oz. Troy	...	195	355	315	833	539
†Value £	...	1,800	4,100	5,400	17,900	9,316

\* Crude.

† Estimated.

‡ Recovered by refiners.

§ The year 1919 has a production of 1,670 oz., valued at £39,614.

\*\* From domestic ores.

The 1917 yield of platinum is estimated to be 116,000 oz., with a value of about £2,240,000, the absorption of which in various industries is considered to be as follows:—Chemical laboratories and industries, 40 per cent.; electrical industries, 25 per cent.; jewellery, 15 per cent.; dentistry, 15 per cent.; other industries, 5 per cent. This shows a very large increase in the demand for it in chemical work.

The annual yields of palladium, iridium, and osmiridium are given in Table 49, in which is shown the prominence given by the United States to the production and refining of these metals. Tasmania greatly increased her osmiridium yields in 1918, while in 1919 there was a further increase in quantity although a small decrease in value.

The exports of platinum given in Table 50 indicate that the only exporting countries at the present time, so far as official returns show, are Colombia and Canada. Most of the Russian output before the war went to France, but apparently all exports from Russia have ceased.

Palladium exports from Canada are not officially recorded, although the metal is produced from Sudbury ore or matte sent to the United States, the figures given in Table 50, therefore, being only estimated.

A large proportion of the osmiridium produced in the world is from Tasmania, and as the metal is exported, the production and export figures are practically the same.

Exports of iridium from producing countries are not obtainable.

Regarding imports of platinum, it has been asserted that before the war 25 per cent. of Russian platinum was imported into Germany, 70 per cent. into England, and the rest into the United States, but France imported from Russia perhaps the whole of the platinum received by England and America, and probably only the imports into Germany were received direct. The statistics in Table 51 show that to credit the United States with only 5 per cent. of the Russian output is entirely wrong.

On the question of platinum imports into France, Mr. Dye, platinum refiner, of Sydney, considers that France refines the platinum herself, and states that before the war it was often possible to obtain the metal cheaper in France than in England.

TABLE 50.—ANNUAL EXPORTS OF PLATINUM METALS BY COUNTRIES, 1914-1918.

Country Exporting.	YEARS.					Country Importing.	
	1914.	1915.	1916.	1917.	1918.		
PLATINUM.							
Colombia	... oz. Troy	12,387	16,298	24,774	23,445	22,974	United States
	Value £	85,053	121,717	349,542	38,717	41,104	
Canada	... oz. Troy	43	236	532	331	197	United States
	Value £	450	2,302	8,738	6,166	4,352	
PALLADIUM.							
Canada	... *oz. Troy	700	250	500	500	300	United States
	*Value £	6,600	2,500	8,700	10,700	6,600	
OSMIRIDIUM.							
Tasmania	... *oz. Troy	1,019	247	222	332	1,609	United States and United Kingdom.
	*Value £	10,076	1,581	1,899	4,898	44,833	

\* Estimated.

NOTE.—Exports of platinum from the United Kingdom before the war were about 3,000 ounces per year, but no official information is available.

Before the war the United States evidently received the greater part of her imports directly or indirectly from Russia, but the war stopped the business, and her imports from all sources were reduced to about half the normal quantity. As the war proceeded, however, a gradual recovery took place on account of the development of the mines at Colombia, and in 1918 the imports of platinum were almost equal to the pre-war imports. The British and French imports, on the other hand, ceased altogether during the war, and there has been no recovery since.

Palladium, iridium, and osmiridium seem to have been imported only by the United States and, apparently, even the yield of osmiridium from Tasmania has been absorbed by that country. Regarding iridium, no locality is indicated as the source of the imports of this metal, but probably it is in the ores received from Colombia.

TABLE 51.—ANNUAL IMPORTS OF PLATINUM METALS BY COUNTRIES, 1914–1918.

Country Importing.	YEARS.					Country Exporting
	1914.	1915.	1916.	1917.	1918.	
	£	£	£	£	£	
PLATINUM.						
United States, refined and crude	619,525	*502,501	657,774	503,157	1,031,775	Chiefly from Colombia and Russia
United Kingdom ...	117,692	¶	¶	¶	¶	
Canada ...	16,598	17,518	18,446	23,808	6,487	
Sweden ...	††26,760	††83,860	..	..	..	
PALLADIUM.						
United States—						Canada
Oz. Troy ...	1,613	...	6,513	1,239	240	
Value £ ...	14,489	21,380	58,939	24,415	7,678	
IRIDIUM.						
United States—						
Oz. Troy ...	1,785	...	3,346	3,619	1,126	
Value £ ...	23,423	50,680	52,230	78,891	26,308	
OSMIRIDIUM.						
United States—						Tasmania
Oz. Troy ...	1,348	...	414	259	427	
Value £ ...	17,576	1,195	3,592	5,303	9,650	

\* This value represents 65,000 oz. About 50,000 oz. of scrap are annually returned for refining, so that a total of about 115,000 oz. of pure platinum goes into consumption.

¶ No imports recorded during the war period.

†† Yield estimated at £9 5s. per oz. refined.

### Prices and Prospects.

Platinum, palladium, iridium, and osmiridium quotations are given in Table 52. The information regarding platinum is fairly complete with the exception of that referring to Russia, and shows the great variations which existed at times between London and New York prices. The Russian prices have been obtainable up to 1917, but since then no details have been made available.

The differences between the New York and London prices during the war, shown in Table 52, are partly due to the British authorities stopping the export of platinum to America, and partly to the demand in America for the metal in the making of high explosives and jewellery, another factor being the limiting of trade only to those licensed to deal, which prevented indiscriminate buying and selling. The developments in Colombian platinum mining and the recovery of platinum in copper refining

works in the United States have almost restored the supply of platinum to normal conditions in America, while prices in London, instead of being lower than those in New York, are now considerably higher.

There is also another feature to be considered in comparing prices. Russian standard platinum grades are based on the presence of 83 per cent. of platinum in the crude metal, while the Colombian standard is 85 per cent. of either platinum or platinum group metals.

No doubt there are considerable quantities of platinum stored up in Russia which will be placed on the market *as soon as the general exports of that country become greater than the imports*, but until that development takes place, and quite irrespective of peace conditions, there will be considerable quantities held in reserve in the banks which will not go into industrial use. With the present outlook, therefore, no apprehension need be felt that the price of platinum will fall permanently to its former standard, at least for many years to come.

Palladium prices, like those of platinum, were high in America and low in England during the war, and for the reason above specified with regard to platinum, the London prices of palladium now much exceed those of New York.

Iridium is quoted at about double the price of palladium, while osmiridium is quoted at £45 per oz. on the Tasmanian fields. This price for Tasmanian osmiridium is due to the demand for the large grains by pen-makers.

Russia, in 1915, endeavoured to create a local platinum refining industry by imposing an *ad valorem* export duty of 30 per cent. on crude metal, but judging by the reports which have been published the endeavour was not attended with success. Colombia, which is increasing its output annually, in 1919 put on a platinum export tax of 5 per cent. *ad valorem*, and no doubt this will have some effect in preventing any tendency to the lowering of prices.

So far as Queensland is concerned there is nothing tangible on which to base an opinion on the prospects of obtaining platinum in payable quantities in either lode or alluvial deposits, but there is a lot to be done in investigating areas where possible supplies exist. Nothing whatever has been done to determine its absence or presence in the alluvial deposits about our serpentine areas, and before any decision can be arrived at the deposits about Kilkivan, Mundubbera, Cawarral, Canoona, Bowen, and other places will have to be examined, more particularly where the serpentines have been disturbed by intrusive dyke masses.

TABLE 52.—AVERAGE ANNUAL QUOTATIONS OF PLATINUM METALS,  
1913-1920.

Year.	LONDON. ¶		NEW YORK. †	RUSSIA. † Crude Metal. 83% Platinum.	
	Refined.	Scrap.		Petrograd.	Ekaterinburg.
	£ s. d.	£ s. d.	£ s. d.	£ s. d.	£ s. d.
PLATINUM.					
	Per Troy oz.	Per Troy oz.	Per Troy oz.	Per Troy oz.	Per Troy oz.
1913 .. ..	9 5 0	..	9 7 0	7 12 3	7 11 0
1914 .. ..	9 5 0	..	9 8 1	7 18 4*	7 17 3*
1915 .. {	9 5 0‡	..	10 6 9	7 10 3	7 3 9
	10 10 0‡				
1916 .. {	9 10 0§	..	17 7 6	13 14 0	13 11 0
	11 0 0§				
1917 .. ..	14 10 0§	13 0 0	21 8 5	16 14 11**	..
1918 .. ..	19 8 0	17 9 0	22 1 5	..	..
1919 .. ..	22 2 0	19 5 0	23 17 7	..	..
1920 (Jan.-June)	30 2 0	24 19 0	25 12 6	..	..
	PALLADIUM.		IRIDIUM.	OSMIRIDIUM.	
	LONDON. ¶ Refined.	NEW YORK. † Refined.	NEW YORK. † Refined.	New York.    Refined.	TASMANIA. Crude.
	£ s. d.	£ s. d.	£ s. d.	£ s. d.	£ s. d.
1914 .. ..	..	9 3 4	13 10 10	6 17 6	..
1915 .. ..	..	11 13 4	17 5 10	7 5 10	..
1916 .. ..	..	13 9 2	19 11 8	9 7 6	10 10 0
1917 .. ..	14 10 0§§	22 18 4	31 5 0	12 10 0	16 15 0
1918 .. ..	18 17 6	28 6 8	36 9 2	..	33 0 0‡‡
1919 .. ..	25 0 0	25 6 3	..	..	21 0 0‡‡
1920 (Jan.-June)	31 16 4	23 10 10	62 10 0	..	45 0 0

\* Estimated, in part.

† Eng. and Min. Journal.

¶ Daily Commercial Reports, London.

‡ Prices subject to negotiation up to Jan., 1916.

§ Government buying price.

|| Mineral resources of the United States, 1917.

\*\* Production taken by Russian Government at this price.

‡‡ Field Prices in November.

‡‡ Field prices in January.

§§ November quotations.

NOTE.—On 14th May, 1918, the U.S.A. Government price was fixed at £21 17s. 6d. per oz. for platinum, £28 2s. 6d. for palladium, and £36 9s. 2d. for iridium. Restriction was removed on 1st Dec., 1918. (Eng. & Mg. Jour.)

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## Article 6.—NICKEL.

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### Queensland Localities.

Lodes containing nickel occur at Mount Coora close to Black Snake in the Kilkivan District, in the Annie Mine at Cawarral, and at the Hector Mine near Rockhampton, while the metal has been recognised as a constituent of glaucophane at Mount Mee and other localities on the D'Aguilar Range, and as a constituent of chrysoprase at Yaamba on the Fitzroy River close to Rockhampton.

### Other Localities.

Within the Commonwealth nickel-bearing deposits occur at Port Macquarie, Ewengar, and Carcoar in New South Wales, and at Zeehan and Trial Bay in Tasmania.

In New Caledonia deposits of nickel ore have been proved to be very extensive and at one time were considered of the greatest importance, but in the Sudbury district of Ontario in Canada other deposits of greater importance have been discovered, and have quite overshadowed the New Caledonian developments.

At the locality named Cobalt and at Dundonald, both in Ontario, other subsidiary deposits have been worked; the deposit at the former place is important so far as silver and cobalt are concerned but the nickel it contains is only of little value.

In Germany nickel-bearing lodes occur at Lausitz in Saxony, and nickel mines were once worked at St. Blasien in the Black Forest, and at Frankenstein in Silesia. In Norway a number of deposits have been opened near Evje and near Ringerike, where the mines are now producing fair quantities of the ore.

Deposits of greater or lesser extent occur in Sweden, France, Italy, Russia, Siberia, Austria, Spain, Switzerland, Hungary, Greece, England, Newfoundland, United States, Cuba, Mexico, Peru, Bolivia, South Africa, Nyassaland, Madagascar, India, China, Borneo, and Egypt.

### Nickel-bearing Minerals.

*Pyrrhotite* (Magnetic Pyrites).—Nickel-bearing sulphide of iron. Lustre, metallic; bronze-yellow to copper-red in colour.

Hardness—3.5 to 4.5; specific gravity—4.6; Composition—2½ to 5½ per cent. of nickel. The most important source of nickel. The commonest of all nickel-bearing minerals. (See note under Pentlandite.)

*Niccolite* (Copper Nickel: Kupfernickel).—An arsenide of nickel. Lustre, metallic; colour, pale copper-red. Hardness—5 to 5.5; specific gravity—7.5. Composition—40 to 49 per cent. of nickel. An important source of nickel. Sometimes the nickel is partly replaced by antimony.

*Chloanthite* (White Nickel).—An arsenide of nickel. Lustre, metallic; colour, steel grey. Hardness—5.5 to 6. Specific gravity—6.5. Composition—10 to 35 per cent. of nickel. Frequently the nickel is partly replaced by cobalt.

*Millerite* (Nickel Pyrites).—A sulphide of nickel. Lustre, metallic; colour, brass-yellow. Hardness—3 to 3.5; specific gravity—5.5. Composition—65 per cent. of nickel. Forms masses in close association with iron pyrites and copper pyrites. An important source of nickel.

*Pentlandite*.—A sulphide of nickel and iron. Lustre, metallic; colour, bronze-yellow. Hardness—3.5 to 4; specific gravity—4.6. Composition—18 to 20 per cent. of nickel. Note—This mineral is found intimately associated with pyrrhotite, in which it is distributed as grains, and from which it is indistinguishable in colour. Possibly all the nickel in pyrrhotite is in the form of this mineral or of polydymite.

*Polydymite*.—A sulphide of nickel. Lustre, metallic; colour, dark iron-grey; hardness—4.5; specific gravity—4.7. Composition—36 to 53 per cent. of nickel.

*Limonite*.—Hydrous oxide of iron. Sometimes forms an outcrop of nickel-bearing lodes. Its presence in large surface masses in the Sudbury area of Ontario is always considered indicative of the existence of a deposit of pyrrhotite below, and in Cuba it forms a lateritic nickel deposit of some value. Generally contains traces of nickel in the form of sulphate (morenosite), or arsenate (annabergite) or oxide (bunsenite); also containing carbonates and oxides of iron, copper and chromium.

*Garnierite* (Noumeite).—A silicate of nickel and magnesia. Colour, apple-green to dark-green; translucent; earthy or unctuous. Hardness—2 to 3; specific gravity—2.5. Composition—4 to 40 per cent. of nickel. The composition is variable, but the New Caledonian mineral contains about 7 per cent. of nickel. Constitutes the second most important source of nickel in the world.

Other minerals containing nickel of varying importance:—

*Meteoric Iron*.—A grey iron-nickel alloy variously containing from 4 to 60 per cent. of nickel.

*Bunsenite*.—The glassy pistachio-green oxide of nickel.

*Iron Pyrites*.—Sometimes contains a small percentage of nickel.

*Copper Pyrites*.—A small percentage of nickel is occasionally present.

*Graünaute* (Nickel Bismuth).—The silver-white sulphide of nickel and bismuth.

*Ullmannite* (Antimonial Nickel).—The steel-grey sulphide of nickel and antimony.

*Tetrahedrite* (Fahlerz).—A grey sulphide of antimony and copper; sometimes contains a small amount of nickel.

*Melonite*.—A metallic reddish-white nickel telluride.

*Gersdorffite* (Nickel Glance).—The dark steel-grey arseno-sulphide of nickel.

*Rammesbergite* (White Nickel).—A steel-grey arsenide of nickel.

*Mispickel* (Arsenical Pyrites).—Sulph-arsenide of iron. Occasionally contains nickel in small quantities.

*Willyamite*.—A sulph-antimonide of nickel and cobalt.

*Annabergite* (Nickel Bloom; Nickel Ochre).—The apple-green arsenate of nickel.

*Morenosite* (Nickel Vitriol).—The light and dark green sulphate of nickel.

*Zaratite*.—The emerald-green hydrated carbonate of nickel.

*Genthite*.—An unctuous apple-green silicate of nickel and magnesia.

*Pimelite*.—An earthy apple-green silicate of nickel and alumina.

*Glaucophane*.—A silicate of alumina, iron, magnesia and soda. Sometimes contains a small percentage of nickel, as at Mount Mee in Queensland.

*Chrysoprase*.—A chalcedony coloured green by nickel.

### Geological Notes.

The principal nickel deposits may be roughly grouped into five types or classes, namely, those principally containing arsenides, which might be considered to be (1) the Niccolite type, (2) those mostly made up of sulphides or the Pyrrhotite type, (3) the silicate or Garnierite type, (4) the Limonite type, and (5) the Asbolane type.

All of these are independent of the other, yet in several ways are closely related, more particularly in regard to the alteration or decomposition of one class of deposit in the formation of another. The decomposition of the arsenides and sulphides in numerous cases has resulted in the production of the silicates, and the further alteration of the silicates has produced the oxides.

The various types in addition to being distinguished by their composition also vary in their rock associations, the arsenides being in a matrix of calcite, dolomite, fluorspar, barytes, or quartz, and rarely in serpentine, the sulphides usually occurring in a matrix of norite (gabbro), a coarse-grained basic intrusive rock. The silicates are invariably in serpentine or peridotite and the oxides in limonite, the brown oxide of iron. The gabbro in some instances has been changed to serpentine, and the serpentine into limonite or ferruginous clays. The change from the gabbro to serpentine appears to take place at the same time as the change from arsenides to silicates, a deposit being occasionally made up of both of these minerals, and sometimes with sulphides in addition.

(1) *Niccolite Deposits*.—These usually consist of several small irregular veins or lenses of arsenides of nickel, cobalt, copper, bismuth, and silver, with sulphides present as subordinate minerals. The deposits at Cobalt in Ontario form a type of this class, and contain cobalt, silver, and nickel, similar occurrences being recorded in Newfoundland, Pennsylvania, Bohemia, France, Saxony, and Carcoar in New South Wales. At Carcoar the deposits are associated with a diorite, with mispickel, niccolite, molybdenite and annabergite present in the lode. At Cobalt in Ontario the nickel is of very subsidiary importance, silver and cobalt being the principal metals.

(2) *Pyrrhotite Deposits*.—The Sudbury deposits in Ontario are the most important in this class, and consist of lenses, irregular masses and pipes of ore in a sheet of norite intruding sedimentary rocks, the minerals being pyrrhotite, pentlandite

and copper pyrites. Arsenides are occasionally present in the ore bodies, together with magnetite, cassiterite (tin), zinc blende, galena, molybdenite, gold, silver, platinum and palladium.

Similar deposits occur in Saxony, Bohemia, Italy, Norway, Sweden, India, South Africa, Tasmania, and Queensland. Those in Queensland are in the Hector Gold Mine, near Rockhampton, and some of the pyrrhotite specimens have yielded two per cent. of nickel. The mineral occurs in masses sometimes a foot thick in association with iron and copper pyrites and is irregularly distributed in a gold-bearing quartz reef several feet wide.

(3) *Garnierite Deposits*.—The New Caledonian deposits are typical of this class, the garnierite occurring as veins, lenses, and concretionary masses widely disseminated in serpentinised peridotite, this rock with other igneous rocks forming intrusions in palaeozoic and mesozoic strata. This type of formation occasionally carries nickel-bearing sulphide in addition to the silicate, but such occurrences are not of importance. Associated minerals are not common. Magnesite is occasionally to be seen on the surface, and asbestos is sometimes present, but chromite is the mineral mostly found.

Garnierite deposits also occur in the United States, Greece, Egypt, Germany, Russia, Madagascar, Tasmania, New South Wales, and Queensland, those in the two latter States, at Ewengar near Grafton, at Mount Coora near Kilkivan, and at Cawarral near Rockhampton being almost identical in their mode of occurrence and in their general geological position with the deposits in New Caledonia.

The Mount Coora deposits are in serpentine in the form of well-defined garnierite-bearing steatite lodes several feet wide, and closely connected with, although distinct from, an adjacent formation of cobalt nickel-manganese asbolane or wad. The extent of these lodes has not been determined, the percentage of nickel present not offering sufficient inducement to further exploit them at the present time. At Cawarral in the Annie Mine the nickel is in serpentine associated with chromium in the form of silicate, with chromite in the vicinity.

(4) *Limonite Deposits*.—The type of this class is that occurring in the Mayari district in Cuba, which consist of a nickel-bearing ferruginous laterite or brown ironstone derived presumably from the serpentine associated with it. The limonite forming the deposit is very hydrous, containing about 50 per cent. of water with varying percentages of silica, alumina, chromium,

and phosphorus. On the island of Sebockoe, Borneo, a limonite deposit exists similar in character to the Cuban deposit, another one being on the Mindanao Island in the Philippines.

A nickelliferous formation containing much moisture and carbonaceous matter occurs at Tunkinsk in the Serguinsk district in Russia. It is a limonite-siderite sediment, and contains the nickel in pyrites in association with cobalt, the carbonaceous character being due to admixture of coal or lignite with decomposed serpentinous material.

(5) *Asbolane Deposits*.—The Port Macquarie deposit of New South Wales is typical of the asbolane or wad occurrences of nickel. The ore is in the form of nests, pockets, and irregular masses of all sizes, and exists either in serpentine or in clays resulting from the decomposition of this rock. The clays are steatitic in part, and sometimes ferruginous and quartz-bearing: the minerals associated with the nickel being cobalt, manganese, and iron, with chromium and copper present in small quantities.

The Mount Coora blue-black asbolane is in the form of irregular masses in decomposed serpentine, and the deposit has been estimated to be 30 ft. wide. Undoubtedly it is very extensive, although the proportion of wad to formation, from what could be seen of the old workings, does not appear to be very great.

### **The Percentages of Nickel in Ore Deposits.**

The pyrrhotite ores of Sudbury average about 4.5 per cent. of nickel, 2.5 per cent. of copper, about 50 per cent. of iron, 34 per cent. of sulphur, and traces of gold, silver, platinum and palladium, the reserves of ore containing these metal percentages amounting to 71,000,000 tons, with a further possible supply of about the same quantity. The values in the matte produced from the ores are from 40 to 50 per cent. of nickel and 25 to 40 per cent. of copper, with 0.1 to 1.0 oz. of platinum, 0.02 to 1.0 oz. of palladium, 0.02 to 0.25 oz. of gold, and 1.8 to 6.0 oz. of silver per ton.

In Pennsylvania some of the ore treated has been found to contain 1.5 per cent. of nickel, about 1 per cent. of copper, and about 0.1 per cent. of cobalt, but the development of the Sudbury deposits caused the discontinuation of mining operations.

In Nevada some very large pyrrhotite deposits were once worked which yielded 3.5 per cent. of copper, 2.5 per cent. of nickel, and 6 dwt. of platinum per ton, but general average quantities were considered to show lower results. In Missouri

a mine worked principally for lead also produced as a valuable by-product a large quantity of ore made up of 3 per cent. of cobalt, 3 per cent. of nickel and 5 per cent. of copper.

In South Africa pyrrhotite deposits at Insizwa contain 3.5 per cent. of copper, 5 per cent. of nickel and cobalt, together with 6 grains of gold,  $2\frac{1}{2}$  dwt. of platinum, and 11 dwt. of silver per ton.

In Norway a lode is being worked which contains about 1.5 per cent. of nickel, 0.01 per cent. of cobalt, and 33 per cent. of copper, while another has been successfully worked containing 1.6 per cent. of nickel, 0.9 per cent. of copper, and traces of cobalt.

In Germany a similar deposit has yielded 1.5 per cent. of copper and 5 per cent. of nickel, while another one is being worked which contains 0.75 per cent. of copper and 2.5 per cent. of nickel. In Sweden a pyrrhotite lode in an abandoned mine contains about 1.5 per cent. of nickel and about 0.7 per cent. of copper, another abandoned deposit in the same country containing 0.6 per cent. of nickel, and 0.1 per cent. of copper.

In New Caledonia the garnierite class of ore when worked formerly averaged 12 per cent. of nickel, but in recent years the rich and poor ores have been blended to produce an average grade of 5.5 per cent. of nickel, of which there are said to be unlimited quantities, the percentage being raised to 6.2 per cent. or over by driving off the moisture from the hydrated silicates forming the garnierite.

The general composition of the garnierite obtained from the working faces ranges as follows:—

COMPOSITION OF GARNIERITE, NEW CALEDONIA.

Moisture ..	22 to 28 %	Ferric oxide ..	5 to 15 %
Loss on ignition ..	9 to 12 %	Magnesia ..	15 to 22 %
Silica ..	45 to 50 %	Nickel ..	4 to 7 %
Alumina ..	1 to 2 %	Chromic oxide ..	0 to 1.5 %

In the United States a North Carolina garnierite deposit containing 2.5 per cent. of nickel was exploited with the object of utilising the nickel in the manufacture of nickel steel, but preliminary trials were not satisfactory and the mine was abandoned.

In Russia a six-foot lode of garnierite-bearing quartz at Revdinsk in the Urals is said to have yielded between 4 and 19 per cent. of nickel on exploitation, but the quantity of the mineral in the quartz was considered too small and all early

attempts to work the lode failed. Recently the mines have started again and operations are said to be giving satisfactory results.

In Greece a deposit of garnierite is found in association with chrome ore, and contains 1 per cent. of nickel and cobalt, with about 2 per cent. of chromium. An Egyptian deposit similar in character contains 9.48 per cent. of nickel, 0.4 per cent. of copper, 15 per cent. of iron, and 0.08 per cent. of chromium.

In Madagascar a discovery has been made of a garnierite deposit which is considered to have a high potential value, the percentage of the nickel in the ore being from 3 to 4 per cent.

In Tasmania a lode of copper-nickel ore has been very successfully worked at Zeehan, the average percentages of mineral being 10 of nickel and 4.5 of copper, the variations in metals being from 4 to 16 of nickel and from 4 to 6 of copper. In Queensland the garnierite lodes of Mount Coora contain from a  $\frac{1}{2}$  to 2 per cent. of nickel, no other important metal being recognised in association with it. The composition of the mineral according to a recent analysis is as follows:—

COMPOSITION OF GARNIERITE, MOUNT COORA, QUEENSLAND.

Moisture	..	..	..	8.4 %	Ferric oxide	..	..	8.7 %
Loss on ignition	..	..	..	15.3 %	Lime	..	..	nil
Silica	..	..	..	39.9 %	Magnesia	..	..	7.1 %
Alumina	..	..	..	19.8 %	Nickel oxide (= nickel 0.7 %)	..	..	0.9 %

At Cobalt in Ontario the niccolite ore contains 3.5 per cent. of nickel, 5.5 per cent. of cobalt, 25 per cent. of arsenic, and 1,100 ounces of silver to the ton, some old records showing that the ore once yielded 9 per cent. of nickel and 10 per cent. of cobalt. The deleterious metals in the cobalt ore are said to make the extraction of the nickel very troublesome and very little value is allowed for it by the smelting companies.

The Cuban laterite or hydrated ironstone deposits are of enormous extent, and in the Mayari district they contain, when dried, about 1 per cent. of nickel, 2.1 per cent. of chromium, 55.5 per cent. of iron, 4.4 per cent. of silica, 4.2 per cent. of alumina, and 0.022 per cent. of phosphorus.

The Russian carbonaceous ironstone occurring at Tunkinsk contains 1.7 per cent. of nickel and cobalt, 35.6 per cent. of moisture, 26.5 per cent. of volatile hydrocarbons, and 14.8 per cent. of fixed carbon.

The asbolane formation at Port Macquarie in New South Wales contains 7.4 per cent. of cobalt, 1.3 per cent. of nickel, and 31 per cent. of manganese dioxide. The deposits at Mount Coora near Kilkivan, when first opened yielded 2.25 per cent. of nickel, and 7.5 per cent. of cobalt, but later tests showed an average of 3.5 per cent. of nickel and 2.7 per cent. of cobalt. Once they were considered to have offered encouragement to development, but the mine is now abandoned.

Mispickel sometimes contains nickel, in which as much as 17 per cent. of this metal has been recorded. Copper pyrites also occasionally contains nickel, from  $2\frac{1}{2}$  to 5 per cent. being the range of nickel percentages.

Generally considered it may be taken for granted that none of the nickel-bearing deposits of the world, so far discovered outside Canada and New Caledonia, carry sufficiently high a percentage of metal to offer any serious competition to the nickel industries in those two countries.

### Metallurgical Notes.

In the extraction of nickel from its ores various fusion processes are usually put into operation for converting the ore either into matte, a concentrated sulphide, or into speiss, a concentrated arsenide, after which various chemical methods are introduced to bring it into solution for chemical precipitation as a nickel compound or for electrolytic deposition as metallic nickel, while at the same time other useful products such as copper, cobalt, iron, silver, gold and platinum are eliminated and saved.

*Nickel Matte.*—If the iron and nickel contained in a mineral, in the form of a double sulphide or as a mineral mixture contained in several metallic sulphides, are heated in a furnace with the necessary fluxes a product is formed which is richer in metal than the untreated ore, the gangue and much of the sulphur at the same time being removed either as slag or as flue gases. When the minerals containing the nickel do not also include sufficient sulphur other mineral sulphides are added. Such mixed mattes might be made up of nickel, cobalt, copper, silver, &c., and require further treatment, usually by “bessemerising,” to convert them into a refined matte, after which they are ready for treatment by chemical and electrolytic processes. The bessemer matte is nearly always made into the nickel oxide used in steel manufacture, 90 per cent. being consumed in this way, while of the remainder 7 per cent. is reduced to pure metallic nickel.

*Nickel Speiss.*—Somewhat similar furnace operations with mineral arsenides produce either nickel speiss, nickel-copper-speiss, cobalt-nickel speiss or other combinations, the proportion of arsenic to metals varying with the treatment. Sometimes sulphides are present with the arsenides, when one or other of the metals combine with the sulphur, the rest forming speiss with the arsenic. Many furnace combinations are possible when arsenic and sulphur are present with nickel, cobalt, iron and copper, and it is the endeavour of the metallurgist to break up these combinations so as to obtain one or more of the metals as oxides free from the others in the form of sulphides or arsenides, the results being achieved by a series of furnace fusions and roastings either in a reducing or oxidising atmosphere.

#### EXTRACTION OF NICKEL.

*Outline of Extraction Processes.*—I. Fusion processes. II. Chemical processes. III. Electrolytic processes. IV. Refining of coarse nickel.

##### I. Fusion Processes.

###### A. Extraction from Ores.

- (1) From Sulphide Ores—making matte, crude metal, and crude alloys from ores containing nickel, iron, copper and sulphur.
  - (a) Roasting the ores in heaps, stalls and furnaces.
  - (b) Smelting the coarse ores to coarse matte.
  - (c) Removing iron from coarse matte to make refined nickel matte or refined nickel-copper matte.
  - (d) Conversion of refined matte into (1) crude nickel, (2) crude nickel-copper alloy, (3) nickel matte free from copper, or (4) refined nickel by Mond process (*see special note further on*).
  - (e) Separation of crude nickel from copper in nickel-copper alloys.
- (2) From Nickel Silicate (Garnierite).
  - (a) Producing nickel-iron alloy direct in blast furnaces.
  - (b) Producing crude nickel-iron matte in blast furnaces.
  - (c) Roasting crude matte to convert most of the iron into oxide.
  - (d) Smelting roasted matte into finer nickel matte and iron slag.
  - (e) Further roasting of nickel matte to nickel oxide.
  - (f) Reduction of nickel oxide to metal.

## (3) From Arsenical Ores.

## (a) Reducing ores to coarse speiss.

1. Direct reduction in furnaces; 2. Roasting the ores, then smelting in furnaces.

## (b) Converting coarse speiss into refined nickel speiss.

## (c) Converting refined nickel speiss into crude nickel.

## II. Chemical Processes.

## (A) Extraction of Nickel direct from Ores.

## (a) Roasting with or without carbonate of potash and sulphur or with common salt, then—

## (b) Treatment with hydrochloric acid or other solutions, then—

## (c) Methods which eliminate sulphur and arsenic, next the iron, and then a final separation of nickel from any cobalt, or nickel from copper, or—

## (d) Treatment by the cyanide process to remove silver by metallic zinc, the nickel in solution being precipitated afterwards.

## (B) Extraction of Nickel from Metallurgical Products.

## (a) Treatment of matte by a roasting process, then its solution in acids to make soluble the iron, copper, cobalt and nickel, and their subsequent separation by various processes—patented or otherwise.

## (b) Treatment of speiss by roasting, and then the separation of lead, silver, copper, nickel and cobalt by somewhat similar processes to that adopted in treating matte.

## (c) Treatment of slags containing nickel as a silicate principally resulting from the smelting of copper-nickel ores.

## III. Electrolytic Processes for Extracting Nickel.

## (1) Precipitation of metals from solutions.

## (a) Chemical precipitation of copper from copper-iron-nickel solutions.

## (b) Chemical precipitation of iron from iron-nickel solutions, then—

## (c) Electrolytic precipitation of metallic nickel.

## (2) Extracting metallic nickel and copper from matte cathodes.

- (3) Production of solutions of nickel and copper chlorides from matte anodes and subsequent chemical or electrolytic treatment of the solutions.

#### IV. Refining Coarse Nickel or Nickel Monoxide.

- (a) Fusion of metal with magnesium.
- (b) Fusion of metal or monoxide with manganese, or manganese alloy, or manganese dioxide.
- (c) Reduction of monoxide by fusion with charcoal in crucibles.

*Scheme for Treating Sudbury Nickel Ores.*—The ore is roasted in heaps to reduce the sulphur to about 10 per cent., after which it is smelted in blast furnaces to produce a low grade matte containing about 33 per cent. of nickel and copper. This matte is bessemerised in a basic converter, the product being a refined matte containing about 80 per cent. of nickel and copper. The refining of the converter or bessemerised matte necessitates the application of many processes to separate from one another the nickel, copper, iron, sulphur, platinum, palladium, gold, and silver, the operations being partly metallurgical and partly chemical. Sometimes a product is required which is made up of metallic nickel and copper, or a matte with certain percentages of copper, nickel, and sulphur, the latter product like the former being utilised in the manufacture of alloys and steels by various patented processes.

*Electric Smelting of Nickel.*—The operations consist of roasting the Sudbury nickel sulphide ore to remove most of the sulphur, then mixing it with lime and coke, and fusing the charge in an electric crucible furnace heated by an alternating current, which reduces the roasted ore to metal. The crucible acts as one electrode, a carbon pencil forms the other, the latter being gradually raised from the charge as the reduction takes place. Some metal obtained in this way was found to contain 40 per cent. of nickel, 28 per cent. of iron, 12 per cent. of carbon, and 15 per cent. of silica, sulphur being absent.—“Mineral Industry.”

*Mond Process.*—This is a method of refining crude metallic nickel, and is based on the fact that nickel will remove carbon from carbon monoxide at a temperature of 50 degrees C. (122 degrees F.), the monoxide being converted into dioxide and the nickel into nickel carbonyl,  $\text{Ni}(\text{CO})_4$ , the latter on further heating reverting to metallic nickel and carbon monoxide. By the application of these reactions finely divided nickel, which has

been reduced from a matte to a metallic state by roasting and bessemerising but containing certain impurities, is acted upon by carbon monoxide in a volatilising tower, and in a vapour form is conveyed into cylinders to be heated to 200 degrees C. (392 degrees F.), and there converted into metallic nickel, the impurities remaining behind in the tower. The carbon monoxide is returned to the tower for a fresh charge of nickel, the operations being repeated until the bessemerised material is exhausted of the metal. The matte for this process is made at Sudbury by the Mond Nickel Company and then sent to Clydach in South Wales where the refining works are established.

*Hybinette Electrolytic Process.*—The low-grade Norwegian ores have been successfully treated by this process, and other works are being established in America to operate it. The process is suitable for the treatment of mattes containing sulphur, nickel, copper, and the precious metals, the contents of the matte treated in Norway yielding about 45 per cent. nickel, 34 per cent. copper, 20 per cent. of sulphur, and less than 1 per cent. of iron.

The operations consist in roasting the matte to remove sulphur, leaching out some of the copper with sulphuric acid, and melting the residue and casting it into anode sheets 3 ft. square, the composition of the sheets being 65 per cent. of nickel, 30 per cent. of copper, and 5 per cent. of sulphur. The copper leached out with acid is also melted into anodes and treated electrolytically, and all slimes are cleaned from base metals and treated for their precious metal contents.

*Alkaline Sulphide Process.*—In this process of treating matte for the extraction of nickel and copper from the Sudbury class of ores, the matte is melted with sulphate of soda in a blast furnace, by which it is converted partly into a heavy matte containing most of the nickel and partly into a light matte containing most of the iron and copper, each matte while molten separating according to its specific gravity, the nickel matte forming the “bottoms,” the iron-copper matte forming the “tops.” By a repetition of the process on each of the bottoms and tops the former will be made to yield a heavy pure nickel sulphide, the impurities being in the tops, while in the tops from the first melting a separation is effected of the remaining portion of the nickel from the copper and iron. The subsequent treatment of the nickel matte and the copper-iron matte consists in leaching to produce purer solutions and residues, the former then being evaporated and both melted into anodes for electrolytic treatment, with a subsequent recovery of

platinum, palladium, iridium and rhodium from the slimes. This is the Orford process adopted by the International Nickel Company at the New Jersey refinery.

*By-Product Nickel.*—Nickel has been found to be present in many copper ores, and the opinion has been expressed that most copper ores contain it in at least small quantities. In the electrolytic refining process the metal gets into the copper electrolyte, and from this it is obtained as a nickel sulphate. It is then reduced to a metallic condition or purified as a salt for nickel-plating purposes.

Many companies in the United States save the nickel as a by-product, and from 100 lb. of blister copper 12 or more lb. of nickel is extracted from the slimes, together with any precious metals.

### **Properties and Uses of Nickel and its Alloys.**

Metallic nickel has a lustre varying between silver-white and steel grey, and will take a brilliant polish. It is very hard, malleable, ductile, has a greater tensile strength than iron, is slightly magnetic (unlike its alloys), and will retain polarity when magnetised. It has a specific gravity of 8.3 when cast, and about 8.9 when rolled. It melts at 1,450 degrees C. (2,642 degrees F.), but combined with carbon fuses at a lower temperature. It can be welded to itself, to iron, and to numerous alloys, and can be rolled into very thin sheets and drawn into very fine wire. When not annealed it is hard under most conditions, and if quenched in water or oil becomes very hard when thin in section, as in the form of tubes, but somewhat softer if in large masses. Nickel in a molten state, like iron, absorbs carbon to the extent of about 6.4 per cent., while below melting point, also like iron, it will absorb carbon if subjected to a process of cementation. A commercial sample of nickel, used for alloys, was found to contain 98.8 per cent. of nickel, 0.16 per cent. of carbon, 0.09 per cent. of silicon, 0.016 per cent. of sulphur, 0.11 per cent. of copper, 0.11 per cent. of tin, and 0.60 per cent. of arsenic. Other analyses are given in Table 53.

Impurities in nickel produce varying effects. Arsenic or sulphur causes brittleness if 0.1 per cent. is present, and copper changes the silvery lustre of the metal to yellow or brownish red and makes it brittle if more than  $1\frac{1}{2}$  per cent. is present, while cobalt increases its silvery lustre, and is said to produce brittleness if more than 6 per cent. is present. Carbon under certain conditions does not affect its good qualities and apparently does not harden it as it will iron. Phosphorus up

to 1·3 per cent. has no deleterious effect, but above this amount produces hardness and lessened malleability, while silicon gives to cast nickel the same effect as it does to cast iron, that is produces softness and increased tensile strength.

The most injurious impurity in metallic nickel is its own oxide, which partly destroys its malleability and reduces its tenacity, the effect being somewhat similar to that of oxide of copper in metallic copper.

Some elements are alloyed with nickel for the purpose of removing other injurious elements, and others are added in mere traces to give to the metal certain qualities which make it suitable for drawing or rolling. If sulphur is present in the metal it is removed by introducing manganese, either as an alloy or oxide, while the tenacity of the metal is increased by adding magnesium.

TABLE 53.—COMPOSITION OF COMMERCIAL NICKELS.

	Ni.	Co.	Fe.	Cu.	C.	S.	Si.
	%	%	%	%	%	%	%
From New Cal. Ore ..	98·23	..	·98	..	..	..	·30
Nickel Cubes ..	99·00	..	·23	·10	·07	..	·12
From "Cobalt" Ore ..	98·00	1·6	·75	·05	..	..	..
Electrolytic Nickel ..	98·75	·5	·10	..	·01	..	..
"International" Nickel	99·08		·46	·10	·05	·02	·05
"Mond" Nickel ..	99·80	..	..	..	..	..	..
Local Sample (Cubes) ..	98·80	..	*	·11	·16	·01	·09

\* Tin, 0·11 per cent. ; Arsenic, 0·6 per cent.

*Ferro-Nickel.*—This alloy is very useful in the manufacture of armour plates, guns, shields, &c. For most purposes it contains from 3 to 7½ per cent. of nickel, but for special uses requiring great tenacity and elasticity it is made with 27½ per cent. of nickel, although some ferro-nickels contain as much as 75 per cent. of nickel. Without carbon this alloy is hard, but with the addition of less than a half per cent. of this element, the hardness is removed. The ferro-nickel produced in the Cockerill Works in Belgium contains 7·5 per cent. of nickel and 0·06 per cent. of carbon. The Bethlehem Works at Chicago produce an alloy containing 3·5 per cent. of nickel and 0·35 per cent. of carbon, while that from the Wittkowitz Works in Austria contains 8 per cent. of nickel and 0·2 per cent. of carbon. By a

cementation process of introducing carbon, that is by continuously heating for perhaps several days at a moderate temperature in a bed of charcoal, the nickel iron is converted into a nickel steel by the absorption of carbon, and plates of the metal on one side may be case-hardened and on the other side remain soft, practically forming nickel-steel and nickel-iron compound plates.

*Nickel Steels.*—A very useful series of nickel-iron alloys is that containing from 2 to 10 per cent. of nickel, while another group which contains from 10 to 20 per cent. of nickel has no practical value at all. A third group contains from 20 to 40 per cent. of nickel, and is specially useful for certain purposes in which the first group has no application.

The steels which contain less than 10 per cent. of nickel with a carbon percentage varying from about 0.12 per cent. to 0.24 per cent. have the property of hardening on being quenched in water or oil, those which contain from 10 to 20 per cent. being neither softened nor hardened by quenching or annealing, while with a percentage above 20 the effect is opposite to that if less than 10 per cent. is added, the steels being softened or, to be more correct, weakened in their physical structure by quenching. A typical nickel steel is made up of the following percentages of ingredients:—Iron, 95.69 per cent.; nickel, 3.33 per cent.; carbon, 0.24 per cent.; manganese, 0.78 per cent.; phosphorus, 0.033 per cent.; sulphur, 0.027 per cent. It is considered that good hardening effects can be produced in such steels if the manipulation is carried out skilfully, but when the steels are made in large masses trouble is sometimes experienced in getting good results.

Certain properties of nickel steels, including tensile strength, elastic limit or fatiguing strain, expansion on heating, electrical conductivity, galvanic corrosion, crystallisation or segregation, and welding properties are all very important to study in connection with the application of these steels to engineering construction. The tensile strength of nickel steels is higher than that of ordinary carbon steels, a quality of great value in making light and strong steel structures, while its elastic limit, which is very great, becomes very useful in withstanding, much more effectively than ordinary steels, the strains set up when moving parts of machinery are not in proper adjustment, as in the bad setting of an engine or propeller shaft. The expansion of certain nickel steels on being heated is equal to that of platinum, and in consequence such steels may be used as substitutes for that metal in various appliances where glass has to be fused around wire

made of it, such as in window glass reinforced with wire netting. The glass has the same coefficient of expansion, and therefore will not crack on cooling after being heated and jointed to either the platinum or nickel steel.

“High-nickel” steels (*see* Table 56) have very little expansion on heating, are very resistant to corrosion, and are practically non-magnetizable—properties of very great importance in some industries. Proportions of nickel and other constituents in these steels can be so arranged that within limits any degree of electrical resistance, expansion on heating, and magnetic permeability in a steel can be obtained. “Platinite” is one of the nickel alloys used as a substitute for platinum in leading-in wires for electric bulbs, its expansion and that of the glass corresponding with one another on heating, while another metal, “Invar” (*see* Table 56), has its composition so adjusted that it has no expansion at all on heating, and is invaluable for the manufacture of scientific instruments requiring as little alteration as possible under changes of temperature.

Non-magnetic high-nickel steels contain over 34 per cent. of nickel and are not effected at ordinary temperatures, but if utilized for any purpose, because of this property, care has to be exercised in preventing their being cooled to  $-40$  degrees F., otherwise they become magnetic and will only become again non-magnetic when heated to  $+1076$  degrees F.

Ferro-nickel chromium is composed of varying amounts of nickel, iron, chromium and carbon, the variations of nickel being from 17 to 19 per cent., of chromium from 50 to 52 per cent., of iron from 28 to 30 per cent., and of carbon from 0.25 to 1.8 per cent. It is a most important alloy and is now being used extensively in structural work. Sometimes vanadium and titanium are used in nickel-chromium steels, but while the former element is fairly well established as a steel constituent, there seems to be some hesitation in adopting titanium as one. In nickel-chromium steels there may be much variation from the compositions shown in Table 56, and this is further accentuated by the heat treatment to which the steels are subjected.

Any tendency of nickel steels to rust becomes less as the percentage of nickel increases, and a steel containing 18 per cent. of nickel is practically proof against the corrosion of weak acid solutions and sea water, while another containing twice this quantity—Invar—is considered to be the best for resisting the formation of rust.

The electrical conductivity of nickel alloys is much less than that of copper, although much greater than that of iron, the effect being reduced to a minimum when the percentage of nickel becomes high. Electrical resistance wire alloys are made up of 20 to 40 per cent. of nickel, and in Table 56 is given the composition of two of them. The "platinoid" alloys are also very useful for the same purpose, and consist of varying percentages of nickel, copper, zinc, and tungsten. One is given in Table 55. Their application is specially useful in the construction of rheostats on account of their electrical and physical properties being unchanged when subjected to heat. The nickel-steel resistance wire, whose composition is given in Table 56, is used extensively in electrical heaters, smoothing irons, and cookers, and for other domestic uses, and also in sparking plugs for internal combustion engines.

Galvanic corrosion takes place between two steels when in contact in either fresh or salt water if one contains nickel and the other only carbon, and while nickel steel plates have many advantages over ordinary steel plates for boilers yet it seems to be recognised that the corrosion is not lessened by the presence of nickel.

The welding of pure nickel, or of a steel containing from 2 to 4 per cent. of nickel, presents no difficulties, but a high nickel steel is troublesome to weld, and it is found in practice that an uniform pressure in welding, such as that applied by hydraulic power, is more effective than a percussion stroke. In all cases, however, simple carbon steels are more easily welded than those containing nickel.

With the right proportion of nickel in a steel the crystallization is less pronounced than in steels without nickel, and steels used in shafting, rock drills, stamper batteries, &c., can effectively withstand alternate strains and stresses if they contain over 3 per cent. of nickel, and between 0.2 and 0.4 per cent. of carbon, while steels containing about  $1\frac{1}{2}$  per cent. of nickel and 1 per cent. of carbon are very tough, and therefore suitable for tools.

In engineering construction some of the nickel steels have been found to be so strong that the size and weight of structures can be considerably reduced without impairing their efficiency, and the standard specifications of the American Society for Testing Material require that structural and rivet steel must contain not less than 3.25 per cent. of nickel.

The crystallization of the constituents of a steel when cooling is an effect which is to be avoided as much as possible, and as

nickel will minimise this tendency it is frequently found advisable to add a few per cent. of it to the steel when in a molten condition, provided the percentages of carbon, manganese, sulphur, and other elements are such that the desirable homogeneous texture is not likely to be impaired.

The nickel in a steel is sometimes augmented by additions of other metals, such as chromium, tungsten, and molybdenum, from which numerous grades are produced having their own special properties and uses. Mayari nickel-chrome steel, an American production, is made from a Cuban ore containing both nickel and chromium, and is typically a structural steel.

*Nickel Alloys.*—Numerous alloys, other than high-nickel steels, are used in the manufacture of high resistance wire (*see* Table 55), and while many do not contain nickel, a large number are made with this element as one of their constituents. In the manufacture of pyrometers the platinum group metals and their alloys are used where high temperatures in furnaces have to be recorded, but thermo-couples for recording temperatures up to 1,000 degrees C. are generally made up of nickel-chromium alloy combined with iron-nickel, nickel-chromium-iron with aluminium-nickel, copper-nickel with copper, or copper-nickel with iron. The electromotive force developed by such combinations in thermo-couples is much greater than that from couples made of platinum group metals and alloys.

Nickel also forms part of the composition of some acid-resisting alloys, the most effective, apparently, being those containing this metal with certain percentages of tantalum, tungsten, and lead.

If made into an alloy containing 5 to 10 per cent. of tantalum its acid-resisting qualities are improved, and if the alloy is made with 30 per cent. of tantalum it will withstand the action of boiling aqua regia. Nickel-tantalum alloys which are tough, and malleable, can be heated to a high temperature without oxidization, and are said to be made by compressing a mixture of the powder of the two metals and then subjecting the mass to a white heat in a reducing atmosphere.

*Nickel-Silver.*—A number of alloys, known by such names as argentum electrum, german silver, packfong, mailshort, and argozoil (*see* Table 55) are varieties of what is generally termed nickel-silver, although containing no silver, and are made up exclusively of copper, nickel, and zinc.

The alloys containing high percentages of nickel, that is,

between 30 and 20 per cent., with varying amounts of copper and zinc are the most suitable for the manufacture of the better class of articles, such as tableware, while 20 to 10 per cent. nickel alloy would be inferior. Other alloys containing less than 10 per cent. of nickel are only used as a basis metal for electroplating. Packfong, one of the nickel-silver varieties, is made in China direct from copper-nickel ores with an admixture of zinc and sometimes with other metals.

In Admiralty specifications it is stated that the nickel-silver used for articles required to be electroplated must contain 16 per cent. of nickel, and large Canadian and American concerns require from 21 to 22 per cent. in the alloy they use as a basis metal. The higher the percentage of nickel the greater is the strength, toughness, malleability and whiteness of the alloy, the lower grades lacking brightness of colour although strong and durable.

The nickel-silver used as above is rolled into sheets, but that required for castings must contain other metals, such as tin, lead, or zinc, the variety called argozoil being considered the best for general use. Other kinds contain small quantities of aluminium or magnesium, the introduction of which prevents the oxidation of the other metals in the alloy.

Nickel-silver solders have a high percentage of nickel and a low percentage of zinc and copper, the composition of two, one hard and the other soft, being given in Table 55.

*Cupro-Nickel.*—The white alloy made up of from 81 to 86 per cent. of copper and from 14 to 20 per cent. of nickel is known as cupro-nickel or “Benedict” metal, and is one of the most useful nickel alloys. It is used very extensively in the making of metal utensils and bullet casings or jackets, and is manufactured by the Colonial Ammunition Company in Melbourne. It is well adapted for rolling and stamping, and electroplaters find it very suitable as a basis metal for their work. (*See Table 55.*)

“In the preparation of cupro-nickel, it is important that copper and nickel of good quality only should be used. The alloy is made by melting the constituent metals together in the usual way in graphite crucibles, but considerable care is needed in its preparation, owing to the high melting point of nickel. Most of the difficulty is experienced in the casting shop. To ensure sound ingots, the metal must be poured “hot” (about 1300 degrees C.), as unsound ingots result if the metal is cast at too low a temperature. The charge varies from about 80 lb. to as much as 260 lb., the average probably being about 120 lb. Experience proves that large charges are to be deprecated. To

ensure sound metal, it is necessary to add a small quantity of some deoxidising agent, usually about 0.1 per cent. of manganese, to the molten metal shortly before pouring. The quantity of manganese to be added is 0.1 per cent. of the total weight of alloy melted, and not 0.1 per cent. of the nickel only." (Ontario Nickel Commission.)

*Monel Metal.*—This is a silver-white alloy so ductile that it can be rolled into very thin sheets and drawn into exceedingly fine wire. It is very little affected by acids or by atmospheric conditions, being about as non-corrosive as copper, melts at 2460 degrees F. (1350 degrees C.), is annealed at 1607 degrees F. (875 degrees C.), and may be worked when heated between 1650 degrees F. (900 degrees C.) and 2190 degrees F. (1200 degrees C.), and welded by electricity or by the oxy-acetylene blowpipe. It has two-thirds the strength of steel under normal conditions, and retains 80 per cent. of its tensile strength when being rolled at the above working temperature, while steel under the same conditions has only 7 per cent. of its normal strength. Its uses are very numerous, more particularly as roof coverings, propellers, parts of machinery submerged in mineral waters, and parts of furnaces and boilers required to stand high temperatures and at the same time retain their tensile strength. When castings are made of it aluminium or magnesium is added to it as a deoxidiser.

The composition of monel metal varies to some extent but its physical properties are not affected very much with slight changes in composition. The percentages of the elements making up the alloy are—nickel, 68 to 72 per cent.; copper, 27 to 32 per cent.; iron, 0.5 to 6.5 per cent.; carbon, 0.072 to 0.15 per cent.; sulphur, 0.014 per cent. It may be made by alloying copper and nickel, but the better method is to make it direct from nickel-copper ores, the Sudbury ores being specially adapted for this purpose. When made in the latter way a matte is prepared containing 22 per cent. of copper and 58 per cent. of nickel, which is roasted to form an oxide and afterwards reduced to metal, the Mond process referred to previously being utilised in the refining of the nickel-copper alloy.

*Nickel Coinage.*—Many countries are now using pure nickel or nickel-bronze in addition to, or instead of, their copper-bronze coinage, although several have used it and have then discarded it. The nickel is usually alloyed with copper to make a bronze, with which silver and zinc is sometimes added, but occasionally the nickel is used unalloyed. When pure nickel is used the stamping of the coins is more difficult than if an alloy is used, but the product is harder and the coins have a brighter colour.

There is a general tendency to substitute pure nickel or nickel-bronze for copper-bronze in coinage, and the British authorities have been considering a proposition to introduce two nickel-bronze coins made up of 22.5 per cent. nickel, 60 per cent. silver, and 17.5 per cent. zinc, the values being ten and five cents, respectively, the British cent to be approximately half that of the American cent.

The Ontario (Canadian) Bureau of Mines has advocated the use of cobalt instead of nickel in coinage, and perhaps some consideration might be given to the same matter in Australia if there is any likelihood of a change. The nickel deposits so far revealed within the Commonwealth are of very little value, while the cobalt deposits near Selwyn in the Cloncurry district give promise of developments, and probably could produce all the cobalt required for an Australian coinage when once the deposits are opened up. The advantages of using cobalt would be its bright white colour, while counterfeiting would be difficult on account of the hardness of the metal.

Pure nickel coinage is being used in Austria, Hungary, Danish West Indies (in part), France, Germany (in part), Mexico (in part), Montenegro, Switzerland, Turkey, and Zanzibar. The countries which use a nickel-bronze coinage (made up of 25 per cent. nickel and 75 per cent. copper) include Argentine, Belgium, Brazil, British Honduras, British West Africa, Ceylon, Colombia, Congo, Danish West Indies (in part), East Africa, Uganda, Egypt, Germany (in part), Greece, Guatemala, Holland, India, Italy, Jamaica, Mexico, Montenegro (in part), Nicaragua, Persia, Siam, Switzerland, Turkey, United States, and Venezuela. —(Nickel Commission.)

*Various Uses.*—The use of nickel in the manufacture of caustic soda has been suggested. Nickel hydrate in the presence of an ammoniated solution of sodium or potassium chloride will form nickel-ammonium chloride and caustic soda or potash, the nickel and ammonia being used again and the soda or potash solutions concentrated. The process is said to be practicable, but has not been tried on a commercial scale. Amongst the innumerable uses to which nickel steel is applied mention may be made of steam hammer pistons, railway axles, crank-pins, engine shafts, cables, armour plates (deck plates specially), gun tubes, rifle barrels and projectiles.

Brasses are improved with nickel in their composition—more particularly when required to be cold-worked—so long as the amount of nickel present does not exceed 10 per cent.

In medicine its compounds are seldom used, but in chemical work crucibles made of it are useful for certain purposes, and as a catalyser it has numerous applications—reference to which is made further on. The gem cutter applies the green monoxide to the polishing of jade and opal matrix, and the same oxide is useful in polishing steel. The pottery-glazer uses it to produce green shades in under-glazes and in-glazes, and mixed with zinc oxide to obtain blue shades. In storage batteries Edison obtains a good result by alternating layers of nickel nitrate with metallic nickel.

*Nickel Catalyst.*—In industrial chemistry metallic nickel, amongst other uses, is applied to the hardening of oils, and is like platinum in being catalytic in its action when in a spongy condition, although differing from that metal in occluding hydrogen and not oxygen. It has the property of carrying hydrogen, which enables it to be used in converting one organic compound into another, such as the oily oleic acid into a solid stearic acid, and so becomes a valuable reagent in the hands of the soap manufacturer. When the catalytic nickel becomes passive by use in this manner, it is oxidized and then again reduced to spongy metal, an operation which makes it once more catalytically active. There are a number of modifications in the use of nickel as a catalyser in the manufacture of stearic acid, but they require careful attention to become effective.

*Nickel Plating.*—All processes of nickel plating depend on electrolytic deposition, the solutions usually being made up of either the double sulphate or double chloride of nickel and ammonia. For special purposes, and sometimes to mix with the above, solutions containing either nickel phosphate, cyanide, citrate, sulphate, or acetate are also employed. In large installations the current is generated by a dynamo, but either a Smee battery, which consists of an amalgamated zinc plate and a platinum-coated silver plate in a sulphuric acid solution, or a Bunsen battery, made of carbon-zinc plates in a similar solution, is used in general practice.

The metallic nickel used in electroplating processes contains tin, iron, silicon, &c., and with such impurities is said to be better for plating than chemically pure nickel. Commercial nickel is made up specially into grades for anodes, the composition of which is shown in Table 54.

TABLE 54.—THREE GRADES OF NICKEL ANODES.

Constituents.					%	%	%
Nickel	..	..	..	..	90·13	81·11	77·72
Iron	..	..	..	..	4·67	12·15	15·16
Tin ..	..	..	..	..	3·20	4·01	3·89
Silicon	..	..	..	..	1·12	1·56	2·17
Copper	..	..	..	..	0·09	0·19	0·11
Carbon	..	..	..	..	0·79	0·98	0·95

Hard metals, such as copper, brass, iron and steel, are generally used as a base for nickel plating, as nickel itself forms a hard surface, the plating not being permanent on such soft bases as lead, tin, pewter, &c. To plate aluminium with nickel the surface is first scoured with hydrochloric acid containing iron chloride which leaves a film on the surface favourable for a close contact between the two metals. The plating of aluminium is not very successful, and if a perfect process could be found many new uses for this metal would be developed.

Nickel will tarnish as readily as silver but such stains are not easy to remove, hence silver-plated articles for domestic purposes are preferred to those which are nickel-plated, even though more costly.

Copper electrotypes and printers' rollers are sometimes plated with nickel to harden their surfaces and as a protection against some of the inks used. Vermilion particularly, when made from mercury, will form a destructive amalgam with copper, which a nickel coating prevents.

Metallic chromium, an exceedingly hard, tough metal, with a bright lustre when polished, would be a very valuable substitute for nickel, but no method has yet been discovered for depositing it on to other metals. Chromium ores are vastly more common in nature than nickel ores, and great quantities exist within the Commonwealth, particularly in Queensland.

*Electrolytic Nickel.*—The process of electrolytically depositing nickel is in some respects like that adopted in precipitating copper, but a greater amperage and a higher voltage is required and the temperatures of the solutions have to be kept higher by steam-jacketing the precipitation tanks. For making thin plates of nickel the solution consists of nickel-ammonia sulphate, but thick plates, which have in the past been troublesome to produce, are now deposited if a hot solution of acid sulphate of nickel is employed.

TABLE 55.—PRINCIPAL NON-FERROUS NICKEL ALLOYS.

Alloy.	Nickel.	Cop- per.	Zinc.	Tin.	Other Constituents ; Remarks.
	Parts.	Parts.	Parts.	Parts.	
German Silver (Elec- trum)	1	2	1	..	For rolling and for making spoons, forks, &c. Good quality ; polishes well. (= Argentum.)
Ditto .. ..	1	3	1	..	Lead, 0.2. Used for casting.
Ditto (Pelouze's) ..	1	1	..	..	A fine white alloy.
Coinage Alloy .. ..	1	3	..	..	Billion ; American 5 cent.
Ditto .. ..	2	7	1	..	Chili coinage.
Ditto .. ..	5	11	2	..	Silver, 2 ; Swiss coinage.
Ditto .. ..	4½	..	3½	..	Silver, 12 ; Proposed British coinage.
Non-magnetic Alloy ..	10	30	9	..	Manganese, 1 ; Iron, 1 ; For watch- springs.
Chinese Silver .. ..	2	10	3	..	Cobalt, 2 ; Silver, 2.
Nickel Silver (English)	5	11	2	..	Silver, 4.
Ditto (Russian)	20	50	14	..	..
Ditto (Solder) ..	25	19	16	..	Hard.
Ditto (Solder) ..	28	18	4	..	Soft.
Cupro-Nickel .. ..	19	80	..	..	Fe, Mn, &c., 1 % (Col. Amm. Co., Melbourne).
Wire Silver Alloy ..	1	5	2	..	Silver, 4 ; can be fine-drawn.
Ruolz Silver (French) ..	5	8	..	..	Silver, 7. For cheap jewellery.
Mousset's Silver ..	1	15	2½	..	Silver, 7½. Has reddish-yellow tinge.
Packfong .. ..	6	8	5	..	= Christoffe metal. Malleable ; white ; sonorous.
Minargent .. ..	7	10	..	..	Tungsten, 5. Has beautiful silver- white colour.
Lemarquand's Alloy ..	7	37½	3½	1	Black oxide of Cobalt, 1.
Argozoil .. ..	7	27	14	1	Lead, 1. For castings.
Luterine (Paris Metal)	32	160	1	4	Iron, 1 ; Cobalt, 2.
Tonca Metal .. ..	4	5	1	1	Lead, 1 ; Iron, 1 ; Antimony, 1 ; hard ; not very ductile ; difficult to fuse.
Monel Metal .. ..	7	3	..	..	See separate heading under Metal- lurgical notes.
Nickel-Manganese-Cop- per	1	24	..	..	Manganese, 8.
Manganese Argentum ..	3	10	1	..	Manganese, 1. Readily casts.
Constantin .. ..	2	3	..	..	Has high electrical resistance.
Nickelin .. ..	16	34	..	..	Has high electrical resistance.
Manganin .. ..	3	21	..	..	Manganese, 1 ; Has high electrical resistance.
Platinoid .. ..	7	30	12	..	Tungsten, 1. Has high electrical re- sistance.
Nickel Chrome .. ..	9	..	..	..	Cr. 1. For thermo-couples.
Turbadium Bronze ..	2	48	46	0.5	Pb. 0.5 ; Fe., 1 ; Al., 0.2. For propellers.
Platinum Bronze ..	90	..	..	9	Platinum, 1. For table ware.
Ditto .. ..	10	..	..	..	Platinum, 1 ; Brass, 21. For orna- ments.
Watch Alloy .. ..	12	12	..	..	Platinum, 42 ; Cadmium, 1.
Jewellery Alloy ..	2	..	..	2	Aluminium, 3 ; Silver, 1.
Ditto .. ..	5	..	..	..	Aluminium, 2.

TABLE 56.—FERRO-NICKEL ALLOYS.

Alloy.	Nickel.	Iron.	Car- bon.	Sili- con.	Other Constituents.
	%	%	%	%	
Nickel-Manganese Steel	20	56	..	..	Manganese, 20.
Ferro-Nickel (Non-Magnetic)	25	74	0.8	0.2	
Ferro-Nickel .. ..	74	25	0.8	0.2	
Ditto (Invar) ..	36	63	0.5	..	Manganese, 0.5.
Ferro-Nickel-Silicon ..	30	15.6	..	47.2	
Ferro-Nickel-Chromium	19	27	0.25	..	Chromium, 52.
Nickel-Tungsten ..	25	..	0.5	0.5	Tungsten, 74.
Ditto .. ..	50	..	0.8	0.2	Tungsten, 49.
Nickel-Molybdenum ..	39	..	0.5	0.5	Molybdenum, 60.
Nickel-Steel Resistance Wire (for Cookers)	30	68	0.4	0.6	Manganese, 1.
Ditto .. ..	25	70	0.6	0.4	Manganese, 4.
Copper-Nickel Steel ..	1.8	96	0.6	0.3	Copper, 1.3.
Nickel-Chrome Steels—					
For Automobiles ..	3.5	94	0.4	..	Manganese, 0.6 ; Chromium, 1.5.
For Armour Plates ..	2.3	97	0.3	..	Chromium, 0.4.
For Projectiles ..	2.0	95	0.8	..	Chromium, 2.2.

### Production.

The statistics of production of nickel are variously divided into nickel ore, metallic nickel, nickel matte, nickel-cobalt ore, and nickel products containing cobalt and other substances. *See* Tables 57 and 58.

Canada, of course, has the world's record for producing the greatest quantity of nickel ore, nearly all of which has been derived from the Sudbury district in Ontario. The output in this area is equal to 60 per cent. of the world's requirements, 50 per cent. alone being furnished by the Creighton mine at Sudbury. The operations are conducted by two companies, the Canadian Copper Company and the Mond Nickel Company, the former producing 75 per cent. of the yield, the latter the remaining 25 per cent. The former company forwards all matte to Constable Hook in New Jersey to be refined by the British-American Nickel Company (The International Nickel Company),\* the Mond Company having the matte treated at Clydach in South Wales.

An Order in Council has been issued by Canada prohibiting the export of nickel matte without a license except to Great Britain, and in view of this the treatment works at Port Colburne

\* The International Nickel Company is said to control the Canadian Nickel Company, the Anglo-American Iron Company, the Orford Copper Company, and a number of nickel-producing mines in Canada and New Caledonia.

at Lake Erie is being constructed by the British American Nickel Company (International Nickel Company) to refine the matte made at Sudbury. During the construction of these works it is understood that a license has been granted to the International Company to manufacture nickel outside the Dominion, that is, at New Jersey.

The New Caledonian nickel ore production is very large, although it could be increased considerably if required. Some time ago the French authorities imposed a heavy tax on unworked mineral lands on the Island, apparently with the object of compelling the Société de Nickel to abandon or work some of their mineral leases, and following this the Company arranged to import Japanese miners and other operatives. At the present time the mines are said to be principally in the hands of the French Company and the International Nickel Company, although it is stated that the mines held by the latter company for some reason are kept idle at the present time. The Japanese are also interested in New Caledonian deposits as owners, and are spending capital in developments, while an order of monks, said to be trading under the name of Ballande and Son, are also operating. The ore and matte produced on the Island is being treated in France, United States, and Scotland.

During recent years Canada has made great strides in her nickel production, as shown in Table 58, her 1918 yield of ore being higher than any previous year, the increase slightly affected no doubt by war conditions, while the New Caledonian production of ore and matte, both in values and quantities, have a downward tendency.

Norway has produced fair quantities of ore from its small ore deposits, nearly all of which has been smelted at Evje and refined at Christiansand. Smaller quantities have been obtained from Sweden, Austria, Hungary, Germany, Russia, Greece, United Kingdom, Mexico, Cuba, Egypt, and Tasmania, some of these countries, however, showing no official records of production. The Cuban deposits appear to give promise of becoming an important producer, although no production statistics are available.

Statistics showing Russian operations are not available, but it is said that deposits on the Urals are now being mined, and that the ore is being treated at the Redwinsk Smelting Works. The last item recorded shows that 600 tons of matte are being produced annually.\*

The figures given in Table 57 are to some extent confusing as a result of the varying methods of compiling returns, but the numerous footnotes will help, to some extent, in explaining the sources of information and the basis on which the returns are built up.

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\* Eng. and Min. Jour., Nov., 1915, p. 759 (vol. 100).

TABLE 57.—TOTAL NICKEL PRODUCTION OF COUNTRIES. *a.*  
(Ore, Metal, and Matte.)

Country.	Year.	Nickel Ore. (Domestic.)			Metallic Nickel and Matte. (Domestic and Foreign.)		
		Tons.	Value. £	Value per Ton. £ s. d.	Tons.	Value. £	Value per Ton. £ s. d.
United States	1876-1904	..	..	..	<i>b</i> 39,117	5,409,410	138 5 9
	1894-1906	..	..	..		<i>c</i> 2,660,681	66 17 6
	1903-1919	..	..	..	<i>d</i> 238,428	<i>d</i> 15,945,983	161 15 10
Canada	1903-1917	..	..	..	<i>e</i> 118,523	<i>e</i> 19,176,144	169 18 2
	1889-1919	<i>f</i> 13,039,928	..	..	<i>g</i> 348,751	59,256,751	
New Caledonia	1888-1918	2,632,327	<i>i</i> 3,762,751	1 8 0			
	1911-1916				<i>j</i> 39,387	1,086,131	27 11 6
Norway	1886-1915	609,034	<i>i</i> 874,180	1 8 8			
	1886-1916		..	..	<i>j</i> 7,202	1,921,991	266 17 5
Sweden	1861-1891	78,202	..	..	..	..	..
	1861-1891	5,273	..	..	..	..	..
France	1914-1916	..	..	..	<i>k</i> 36,950	5,207,544	140 18 9
	1879-1913	..	..	..			
Germany	1852-1901	21,832	46,652	2 2 8	<i>l</i> 27,867	7,067,775	253 12 6
	1902-1913	126,447	..	..	<i>m</i> 43,032	7,740,000	179 17 4
Austria	1856-1901	<i>o</i> 2,973	61,800	20 13 0	<i>n</i> 328	27,765	84 13 0
Hungary	1863-1897	<i>p</i> 11,652	532,646	45 14 3	1,474	91,170	61 17 0
United Kingdom	1873-1890	<i>p</i> 1,264	6,784	5 7 4	..	..	..
Tasmania	1914	<i>q</i> 3,089	15,815	5 2 4	..	..	..

*a.* Compiled from various sources.

*b.* From domestic and foreign ores.

*c.* From imported nickel ore and matte. Nickel contents not stated.

*d.* Production is from imported nickel ore and matte.

*e.* Production of metallic nickel. Estimate based on exports.

*f.* Ontario ore principally. Contains copper and precious metal, but exclusive of nickel in ore from cobalt (locality).

*g.* Figures based on nickel in matte and nickel exported.

*h.* Figures to 1912 from "Statistique l'Industrie ou France et en Algérie" (published by the French Government), 1913-1917 from "Mineral Industry Engineering Mining Journal," New York, &c.

*i.* Estimated (in part).

*j.* From domestic ore.

*k.* Metal principally from New Caledonia ore.

*l.* Nickel products; nickel in cobalt products not included.

*m.* Metal from New Caledonia and Norwegian ore.

*n.* Principally metallic nickel, with cobalt, bismuth, &c.

*o.* Nickel and cobalt ore (in part estimated).

*p.* Nickel and cobalt ore.

*q.* Copper-nickel ore.

TABLE 58.—ANNUAL NICKEL PRODUCTION OF COUNTRIES, 1914-1918 *a*.  
(Ore, Matte, and Metal.)

Country.	Years.					
		1914.	1915.	1916.	1917.	1918.
United States—						
<i>b</i> Metal .. ..	Tons	373	734	819	359	394
Value of metal ..	£	65,203	112,130	139,832	69,076	83,542
Value per ton ..	£	146 1 1	152 15 4	170 14 8	192 8 2	212 0 8
Canada—						
<i>c</i> Ore .. ..	Tons	896,754	1,217,900	1,398,512	1,348,072	1,465,729
<i>d</i> Metal .. ..	Tons	20,321	30,392	36,873	37,399	43,648
<i>g</i> Value of metal ..	£	1,052,627	1,574,305	1,858,500	1,869,314	2,181,483
<i>g</i> Value per ton of Ore	£	51 16 0	51 16 0	50 8 0	49 19 7	49 19 7
New Caledonia—						
Ore .. ..	Tons	<i>e</i> 169,000	<i>e</i> 86,600	<i>e</i> 74,300	<i>e</i> 77,100	<i>e</i> 43,800
Value of ore ..	£	<i>e</i> 165,300	<i>e</i> 116,900	<i>e</i> 100,300	<i>e</i> 104,100	<i>e</i> 59,000
Value per ton ..	£	0 19 4	1 7 0	1 7 0	1 7 0	1 7 0
Matte .. ..	Tons	5,275	5,440	5,659	6,217	3,875
Value of matte ..	£	<i>e</i> 126,800	<i>e</i> 152,300	<i>e</i> 158,500	<i>e</i> 174,000	<i>e</i> 108,500
Value per ton ..	£	24 0 0	28 0 0	23 0 0	28 0 0	28 0 0
Norway—						
Ore .. ..	Tons	47,762	75,800	<i>f</i>	<i>f</i>	<i>f</i>
Value of ore ..	£	25,839	40,300	..	..	..
Value per ton ..	£	0 10 10	0 10 8	..	..	..
Metal .. ..	Tons	781	877	787	<i>f</i>	<i>f</i>
Value of metal ..	£	..	<i>e</i> 234,200	<i>e</i> 210,000	..	..
Value per ton ..	£	..	267 1 0	266 16 8	..	..
Sweden—Ore .. ..	Tons	..	1,616	3,504	<i>f</i>	<i>f</i>

*a*. Compiled from various sources.*b*. By-product in the electrolytic refining of copper.*c*. The ore contains nickel, copper, cobalt, and silver.*d*. Nickel contained in matte, exclusive of copper.*e*. Estimated.*f*. Production is said to be going on, but figures are not available.*g*. Value based on nickel in matte, not of re. ned nickel.

TABLE 59.—EXPORT OF NICKEL FROM COUNTRIES, 1914-1918.

(Ore, Matte, and Metal.)

Country Exporting.	Years.					Country Importing.	
	1914.	1915.	1916.	1917.	1918.		
United States— Metal .. .. Value of metal Value per ton	Tons £ £	12,319 1,969,902 159 18 8	11,794 2,110,107 178 1 4	14,912 2,698,436 180 19 1	9,818 1,861,796 189 12 7	7,799 1,443,133 185 0 10	United King- dom, France, Netherlands, and other countries.
Canada— <i>a</i> Metal .. .. Value of metal Value per ton of ore	Tons £ £	20,772 1,072,797 51 3 3	29,647 1,540,509 51 19 3	35,911 1,804,621 52 10 6	36,281 1,814,302 50 0 2	39,053 2,346,510 60 1 8	United King- dom, United States
New Caledonia— Ore .. .. Value of ore .. Value per ton Matte .. .. Value of matte Value per ton	Tons £ £ Tons £ £	92,666 <i>b</i> 124,700 1 7 0 5,275 <i>b</i> 126,800 24 0 0	47,710 <i>b</i> 64,200 1 7 0 5,440 <i>b</i> 152,300 28 0 0	32,823 <i>b</i> 44,200 1 7 0 5,659 <i>b</i> 158,500 28 0 0	31,511 <i>b</i> 42,400 1 7 0 6,217 <i>b</i> 174,000 28 0 0	15,361 <i>b</i> 20,700 1 7 0 3,875 <i>b</i> 108,500 28 0 0	France, princi- pally; also United States and United Kingdom.
Norway— Metal .. ..	Tons	685	749	713	..	..	

TABLE 60.—IMPORTS OF NICKEL BY PRINCIPAL COUNTRIES, 1914-1918.  
(Ore, Matte, and Metal.)

Country Importing.		Years.					Country Exporting.
		1914.	1915.	1916.	1917.	1918.	
<i>United States—</i>							
Ore matte ..	Tons	29,564	45,798	59,741	54,512	59,621	Canada principally; also from New Caledonia.
a Metal ..	Tons	15,620	25,253	32,416	33,710	32,675	
Value of metal	£	1,032,593	1,586,666	2,060,284	2,002,582	2,399,488	
Value per ton of ore	£	66 2 1	62 16 7	63 11 2	59 8 1	73 8 8	
<i>France—</i>							
Metal ..	Tons	1,543	1,347	1,019	550	..	United States.
Value of metal	£	250,702	234,246	229,544	117,105	..	
Value per ton	£	162 8 3	173 18 0	225 5 3	212 18 4	..	
Metal ..	Tons	1,580	2,482	2,402	..	..	
<i>United Kingdom—</i>							
a Metal ..	Tons	20,772	29,649	35,911	36,300	..	Canada.
Value of metal	£	1,070,922	1,540,510	1,800,829	1,814,302	..	
Value per ton of ore	£	51 11 2	51 19 2	50 2 11	49 19 7	..	
a Metal ..	Tons	4,838	6,608	7,404	6,432	..	
Value of metal	£	805,565	1,107,819	1,289,797	1,162,209	..	United States.
Value per ton	£	166 10 1	182 15 7	174 4 0	180 11 4	..	
<i>Netherlands—</i>							
a Metal ..	Tons	382	58	234	..	..	United States.
Value of metal	£	48,345	11,657	47,481	..	..	
Value per ton	£	126 11 8	200 19 7	202 18 1	..	..	
<i>Italy—</i>							
Metal ..	Tons	b c 570	b c 1,056	a 1,211	a 2,442	..	United States.
Value of metal	£	..	..	331,257	498,481	..	
Value per ton	£	..	..	273 10 11	200 2 6	..	
<i>Russia in Europe—</i>							
Metal ..	Tons	b c 83	b c 1,822	a 3,468	a 75	..	United States.
Value of metal	£	..	..	627,208	13,479	..	
Value per ton	£	..	..	180 17 1	179 14 4	..	
<i>Russia in Asia—</i>							
Metal ..	Tons	..	b c 635	a 510	..	..	United States.
Value of metal	£	..	..	97,260	..	..	
Value per ton	£	..	..	190 15 0	..	..	
<i>Japan—</i>							
Metal ..	Tons	..	b c 138	a 109	a 123	..	United States.
Value of metal	£	..	..	22,764	27,952	..	
Value per ton	£	..	..	208 16 10	227 5 2	..	
<i>Germany—</i>							
Metal ..	Tons	b c 4,948	b c 460	..	..	..	United States.
<i>Belgium—</i>							
Metal ..	Tons	b c 549	b c 94	..	..	..	United States.

a. Includes only the nickel contained in ore and matte.

b. Fiscal year ending June.

c. Nickel, nickel-oxide, and matte.

The quantities of nickel ore, matte, and metal given in Table 59 show the great amount of nickel exported from Canada to the United States in recent years, the amount exported in 1914 being nearly doubled in 1918, with the value more than doubled in the five-year period. The exports of metal from the United States to other countries is also very great, nearly all of the metal, however, being obtained from imported Canadian ore and matte. New Caledonia is shown to have exported larger quantities of ore in 1914 than in 1917, although the exports of metal in matte in 1916 and the four previous years have been fairly constant. The exports of ore and matte in recent years are given in Table 59, and show a considerable reduction in the year 1918.

The imports of nickel ore, matte, and metal by countries given in Table 60 indicate the United States to be the most important country in the world in the nickel manufacturing industry, with the United Kingdom and France next in importance. The United Kingdom imports in 1914 were small compared to those of 1915, while the 1916 and 1917 figures show much greater increases. The Netherlands, which absorbed large quantities of nickel in 1911, gradually reduced her imports in later years. France's imports are reduced to insignificance, while Italy during the war considerably increased hers.

### Nickel Quotations.

If unofficial reports are to be credited there has been some unreliability in the quotations published periodically in the usual channels, these quotations, it has been pointed out, being obtained from interested parties and not from genuine stock exchange reports. Judging from the many inconsistent reports published it is easy to believe that a similar unreliability exists in respect to the statistics on nickel production. However, such as they are, the quotations from 1911 to 1920 are given in Table 61.

At the end of 1912 and during 1915 *electrolytic* nickel was quoted at £14 per ton extra, but in intermediate years the price of this quality of metal was £13 per ton above ordinary brands.

In the years 1916-1919 electrolytic nickel was quoted in New York at £23 per ton (2½d. per lb.) extra, and in 1920 £11 per ton (1d. per lb.) extra.

TABLE 61.—NICKEL QUOTATIONS, 1911-1920.

Year.	New York per Ton.*				London, per Ton.†				Variations, per Lb.			
	£	s.	£	s.	£	s.	£	s.	s.	d.	s.	d.
1911 .. ..	186	10	to	210 0	167	10	to	171 0	1	6	to	1 11
1912 .. ..	186	10	to	210 0	167	10	to	171 0	1	6	to	1 11
1913 .. ..	186	10	to	210 0	167	10	to	171 0	1	6	to	1 11
1914 .. ..	186	10	to	210 0	167	10	to	206 0	1	6	to	1 11
1915 .. ..	186	10	to	233 0	186	0	to	225 0	1	8	to	2 0
1916 .. ..	209	10	to	233 0	220	0	to	230 0	1	11	to	2 1
1917 .. ..	209	10	to	256 10	199	0	to	225 0	1	9	to	2 4
1918 .. ..	186	0	to	233 0	195	0	to	250 0	1	8	to	2 3
1919 .. ..	186	0	to	196 0	195	0	to	215 0	1	8	to	1 11
1920 (Jan. to June)	201				215	0	to	230 0	1	9	to	2 1

\* "Engineering and Mining Journal."

† "London Mining Journal" and "Daily Commercial Reports," London.

### Nickel Prospects in Queensland.

In prospecting for nickel ores in Queensland the serpentines appear to be the rocks in which to expect the most promising deposits, although in the rocks of the gabbro family, which abound in many localities, there are also other possible sources.

Large areas of serpentine country occur about Cawarral and Canoona near Rockhampton, and serpentinous rocks are to be observed about the Calliope River, south-west of Gladstone, while other deposits are known at Mundubbera, Kilkivan, Copperfield near Clermont, Kandanga, Mount Pring near Bowen, and Pine Mountain near Ipswich. In most of these localities chromite and manganese have been found but nickel-bearing minerals appear to be confined to the Kilkivan area and Cawarral.

In the serpentines the green silicates are the usual form in which the nickel occurs, but as these rocks decompose into reddish earthy formations, nickel might be present in such deposits without showing any green colour indications. The gabbros, which are very coarse intrusive basic rocks, should also be examined for nickel, in this case the mineral occurring probably in the form of sulphides and arsenides, with a decomposed outcrop consisting of ironstone. On such weathered out-

crops indications of nickel are not to be expected, although annabergite, the green arsenate of nickel, and scorodite, the greenish arsenate of iron, might be found as decomposition products of arsenides, while cobalt usually associated with the nickel is generally indicated by the blue-black manganese wad or by the pinkish efflorescence in cavities in the ironstone.

The enormous resources of Canada with her hundreds of millions of tons of available nickel ore will always be a deterrent to nickel prospecting developments within the Commonwealth. Whether any developments would follow any rich discoveries within Australia is a question difficult to answer, but beyond doubt in any contemplated developments Commonwealth assistance would be required to face the strenuous opposition which would certainly be made by those controlling the great nickel mines in other parts of the world.

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# Article 7.—GRAPHITE.

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## Article 7.—GRAPHITE.

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### Queensland Localities.

The most interesting occurrences of graphite recorded in the State up to the present time are at Mount Bopple near Tiaro, close to the North Coast Railway line, Cape Upstart on the coast between Bowen and Townsville, and on the Croydon Goldfield in the north-west portion of the State. Other localities where it has also been found include Hampden near Cloncurry, Hamilton Goldfield on Cape York Peninsula, Thornborough in the Chillagoe District, Fossilbrook near the Etheridge Railway line, Herberton, Yorkey's Goldfield north of Kilkivan, Glenroy near the Boomer Range in Central Queensland, Homebush south-west of Mackay, Gympie, near Gutchie Railway Station, Mount Marley near Stanthorpe, Bunya Bunya Range north-east of Jandowae, Cutella near Toowoomba, and Silver Spur near Texas. Some of these locality references are given in the Queensland Mineral Index but concerning most of them very little information is available.

### Other Localities.

Within the Commonwealth a number of graphite deposits occur in New South Wales, those at Undercliff near Wilson's Downfall on the Macpherson Range border and those at Walcha being considered the most promising. South Australia has a number of interesting deposits about Arno Bay, Sleaforth Bay, and other localities on Eyre Peninsula, and Western Australia has one at Donnelly River in the Plantagenet District and another at Munghlinup in the Eucla Division which show favourable indications, while Tasmania has recorded occurrences at Zeehan, Dundas, and Severn River. In New Guinea graphite deposits have been observed over a large extent of country in schistose rocks, but nothing has been done to determine their value.

The most important deposits of the world occur in Ceylon, the next in potential value being those of Madagascar. The United States has a number of valuable graphite deposits, also Austria, Canada, Italy, Germany, Mexico, India, and Korea (Chosen), while other countries in which graphite deposits are

known or where small quantities have been obtained include England, Spain, Siberia, Russia, Alaska, Japan, South Africa, New Zealand, France, China, Sweden, and Norway.

### Mineral Notes.

Graphite is commonly known as Plumbago and Black Lead, and an old name for it is Carburet of Iron. Scientifically it is divisible into three classes, viz., *crystalline*, *flake*, and *amorphous*, the Ceylon plumbago being a type of the crystalline variety, which is massive, the Madagascar graphite a type of the flake variety, which is in scales, and the Mexican a type of the “amorphous,” which is micro-crystalline. Its physical properties are as follows:—Colour—steel-grey to blue-black; hardness—1 to 2; marks paper; sectile; opaque; flexible, not elastic; usually in scales, sometimes fibrous and massive; feels greasy; lustre—sub-metallic, sometimes dull and earthy; specific gravity 2.1—2.3. Somewhat resembles molybdenite, but this mineral has a distinctly bluish tinge with an equally distinct metallic lustre, besides having very fine lamination or leaves and a very perfect cleavage which graphite does not possess. Some forms of graphite much resemble anthracite, and the two merge into one another.

Graphite is principally made up of carbon, with iron, alumina, and silica present in amounts varying from less than 1 per cent. to several per cent. In its composition it somewhat resembles charcoal, coke, lignite, coal, anthracite and diamond, the graphite taking up a position between the amorphous anthracite and the crystalline diamond. It is slowly combustible (combines with oxygen) at 650 deg. C. to 700 deg. C. and fuses or volatilizes at about 3,000 deg. C. It is a good conductor of both electricity and heat, these properties making it exceedingly useful in many industries.

Graphite in an “amorphous” condition is always dull, although it becomes lustrous by rubbing, while the flaky or scaly graphite is naturally bright and glistening. Sometimes a graphite appears dull on casual examination yet may be seen to be minutely crystalline when closely examined. Black plastic clays containing a few per cent. of coaly matter or graphite will also become bright with rubbing and may have the general appearance of a rich graphite.

The best form of graphite is that known as plumbago, the next best grade is flake, and the thicker the flakes the better, the lowest being amorphous or micro-crystalline.

TABLE 62.—GRAPHITE ANALYSES.

LOCALITIES.	COMPOSITION OF GRAPHITES.			COMPOSITION OF ASH.				
	Fixed Carbon.	Volatile Matter.	Ash.	Silica.	Alumina.	Iron.	Lime and Magnesia.	Loss, &c.
	%	%	%	%	%	%	%	..
Ceylon (commercial) .. ..	68.30	5.20	26.50	50.3	41.5	8.2	..	..
Ceylon (refined) .. ..	99.28	0.30	0.41	..	..	..	..	..
Bagoutal, Irkutsk, Siberia ..	38.00	5.80	56.00	22.4	2.35	7.64	0.68	..
Passau, Bavaria .. ..	81.08	7.30	11.62	53.7	35.6	6.8	1.7	2.2
Schwarzbach, Bohemia .. ..	88.05†	1.05	10.90	62.0	28.5	6.3	1.5	1.7
Zaptan, Austria .. ..	90.63	2.20	7.17	55.0	30.0	14.3	..	0.7
Pissie, France .. ..	59.67	3.20	37.13	68.7	20.8	8.1	1.5	0.9
Hafnérluden, Moravia .. ..	..	..	52.50	49.2	2.0	0.8	..	..
Vagerita, Sweden .. ..	87.63	1.55	10.81	58.6	31.5	7.2	0.5	2.2
Monte Pisano, Italy .. ..	48.88	8.65	42.25	..	..	..	..	..
Borrowdale (ordinary), England..	84.38	2.62	13.00	62.00	25.0	10.0	2.6	0.4
Ticonderoga (vein), New York ..	98.81	0.90	0.23	..	..	..	..	..
Buckingham, Canada .. ..	97.62	0.59	1.78	45.73	10.82	1.23	35.69	6.35
Renfrew, Canada (vein) .. ..	76.75	3.55	19.75	65.80	25.1	6.2	..	1.70
Ceara, Brazil .. ..	77.15	2.55	20.30	79.0	11.7	7.8	1.5	..
Madagascar .. ..	70.69	5.18	24.13	59.6	31.8	6.8	1.2	0.6
La Colorado, Spain .. ..	86.75	..	13.25	..	..	..	..	..
Arno Bay, S. A. .. ..	50.80	3.00	46.20	63.1	28.5	4.5	..	3.9
Wilson's Downfall, N.S.W. ..	31.76	8.66	59.58	..	..	..	..	..
Fairview, N.S.W. .. ..	47.12	11.88	46.27	..	..	..	..	..
Collingwood, New Zealand ..	66.86	0.85	32.29	..	..	..	..	..
Nelson, New Zealand .. ..	52.12	2.02	45.86	..	..	..	..	..
Hampden, near Cloncurry, Q. ..	17.60	10.30	72.00	..	..	..	..	..
Bull's Mine, Mt. Bopple, Q. ..	74.10	1.10	24.00	..	..	..	..	..
Simpson's Mine, Mt. Bopple, Q...	32.28	5.32	62.44	58.30	35.80	..	1.30	5.00
Drain's Mine, Mt. Bopple, Q. ..	72.70	6.20	21.00	..	..	..	..	..
Imported Sample (facing) ..	35.90	4.60	59.40	..	..	..	..	..
Gas Retort Carbon .. ..	92.42	0.17	7.25	68.6	28.6	2.2	..	0.5

† Best quality; general average is from 50 to 60 %.

### Geological Notes.

Graphite occurs in igneous, metamorphic, and sedimentary rocks under varying conditions, but it is in the two former groups that the most valuable deposits are to be found. Amongst

igneous rocks it has been observed as masses, veins, lenses, and scales in granite, syenite, diorite, &c., and in association with quartz, felspar, calcite, hornblende, &c. Its dissemination as scales in granite is an indication that this rock may have been a sediment, and became changed by metamorphic action to its present form, the graphite representing an old coal deposit or a previously existing carbonate formation. Veins of graphite in granitic and metamorphic rocks are due in a great measure to the deposition of the carbon in open spaces from a state of vapour.

The Ceylon graphite deposits are principally in the form of veins, which occur in great numbers and several inches thick in schistose or gneissic rocks, but the mineral also exists throughout the rocks as scattered flaky grains. When massive it is referred to as "plumbago," while the scattered grains in the rock are called "flake graphite."

The granites of the Croydon Goldfield in this State contain disseminated graphite within a defined zone or belt, and the line of weakness developed along this zone as a result of the presence of the graphite has resulted in the formation of a long line of reef richly gold-bearing.

Metamorphic rocks of all kinds have been found to contain graphite, crystalline limestones in particular being an associate of quite a number of deposits, the graphite occurring in the limestone as scales but more frequently as veins or interbedded masses. The Canadian deposits of Buckingham and Grenville are in metamorphic rocks, and are usually associated with limestones, the graphite forming principally as veins.

The Ticonderoga deposits of New York are in granites, pegmatites, schists and limestones, the graphite occurring as veins and as disseminated scales. The Madagascar graphite is in the form of scales, flakes and veins in soft gneissic rocks, and is said to much resemble the Ceylon occurrences. The impurities in the graphite include felspar, quartz, mica and other minerals found in pegmatite. The Italian deposits in the district of Pinerolo, Piedmont, are in a garnetiferous mica schist, the beds of graphite varying from a few inches to 10 ft. in thickness.

The graphite deposits on Eyre Peninsula, in South Australia, and those at Munglinup in Western Australia are in metamorphic rocks, and at Walcha in New South Wales the mineral occurs in finely disseminated scales in a pegmatite dyke traversing granite, the dyke being well defined and varying in thickness up to 30 ft.

Sedimentary beds containing coal seams when disturbed by igneous intrusions become metamorphosed along the zone of contact, the sandstones being changed to quartzites, the shales to cherts, and the coal to anthracite and graphite. The Mexican and Korean deposits are made up of amorphous graphite produced in this way, the former being considered the largest in the world of its class, the graphite occurring in beds about 10 ft. thick in altered sandstone and conglomerates, which granite dykes have penetrated and disturbed.

The Mount Bopple graphite beds have been proved to be very numerous and are sometimes several feet thick. They belong to altered Mesozoic coal measures, the coal seams being "graphitized" by intrusions of syenitic granite and quartz andesite. There are several unaltered coal seams in the neighbourhood, but immediately around Mount Bopple and the country to the south near Beacon Peak, three-quarters of a mile from Mount Bopple, several intrusive masses are to be seen, which have altered the whole of the coal seams between the two mountains. Many of the seams are very high in ash, but prospecting operations near igneous intrusions would no doubt reveal some that would have the low ash contents of a number of the unaltered coal seams in the district. One graphite seam in Bull's Mine on the eastern slope of Mount Bopple is a foot thick, the analysis of which is given in Table 62, while about a foot below there is a seam of anthracite containing 4 per cent. of ash.

At Cape Upstart a seam of graphite from 4 to 8 ft. thick occurs in coal measure strata, the alteration of coal to graphite being caused by a massive igneous intrusion. No particulars are available, however, concerning the character or quality of the graphite.

In New South Wales, near the Queensland border, graphite occurs at Undercliff close to Wilson's Downfall, and also near the border at Killarney, both occurrences being similar to those at Mount Bopple in character, quality, and geological occurrence, and doubtless have been formed by the same agencies.

In New Zealand graphite is commonly found in metamorphic and other rocks, and a probability exists of workable deposits being unearthed if search were made, specially in north-west Nelson (Morgan).

Amorphous graphite with anthracite occurs interbedded with the sedimentary rocks of the Gympie Goldfield. It is not a freshwater deposit, the sandstones and conglomerates closely associated with it containing abundance of marine shell fossils,

with a great thickness of volcanic ejectments and contemporaneous volcanic flows occurring in the same series. This deposit has no value from a graphite point of view, but the mineral has been the precipitant for the gold in the quartz reefs which cross the strata containing bands or beds of it, the gold only occurring where the graphite comes directly in contact with the reef or lode.

Graphite deposits do not always show surface indications, and a bed or vein of the mineral might exist with a ferruginous, clayey or siliceous capping and nothing whatever to show its presence below.

The mineral is also present in meteorites, and a recent examination of one of the large undescribed Queensland meteorites has revealed the presence of graphite nodules in the interior of a mass of nickel-iron. In the manufacture of iron in blast furnaces graphite is formed as one of the essential constituents of pig iron, and if this iron be dissolved by acids a graphite residue remains which consists mostly of fine crystalline flakes. The noted Peak Downs copper mine at Clermont was abandoned many years ago, and when subsequently unwatered the large iron pump columns fixed in the main shaft were found to have had all the iron leached out by the acid mine water. The columns were quite hard and firm although only the graphite and some other insoluble constituents of the original iron were left behind, and the columns were only one-twentieth of their original weight.

### **Concentrating and Grading Graphite.**

Mining operations are carried on in various ways, all more or less along lines well established, from the primitive methods of India to the modern systems of Europe and America. The separation of graphite from its gangue minerals, however, is an operation attended by so many difficulties that quite a record is established for failures in handling graphite mining and concentration propositions, and this is due not so much to poorness of yields as to the instalment of mechanical appliances quite unsuited to the work. Each deposit has to be studied on its own merits, with a scheme worked out according to the results of experiments on bulk samples.

The preliminary operations in dressing the mineral consist in handpicking the graphite lumps, then sufficiently reducing the remainder, by means of rolls or rock crushers, to pass through  $\frac{1}{2}$ -in. mesh screens. The ore is then steam-dried and further reduced in rolls or ball mills to release all the graphite from the

gangue, and washing machines then concentrate the graphite into a higher percentage product. Buhr mills, wire sieves, silk bolting reels, and air separators remove the remaining trace of grit and produce several grades in quality and size.

The greatest difficulty sometimes exists in separating graphite from its associated minerals, and in some instances where there is, say, 20 per cent. of the mineral in the rock to be hand-picked and milled, perhaps 5 per cent. is not recovered, while of that saved the lower grades are of little value because of their extreme fineness of grain.

The grinding and concentration no doubt presents many difficulties simply from the fact that the graphite has a lubricating action on the grit or matrix with which it is associated, and therefore has a tendency to pack or cake in the grinding machines. The presence of mica in the graphite matrix is also very undesirable, and it is found almost impossible by mechanical means to separate this impurity from graphite when in a flake form, and very often a mining proposition that otherwise would be successful turns out to be a commercial failure from this cause. When graphite and chlorite are contained in the same deposit it is sometimes convenient to work the product into a foundry facing which does not require a high percentage of graphite, as a mixture of the two "sleeks" very well when used as a facing on sand moulds.

Oil flotation has been experimented with in separating graphite from its gangue, the mineral being found to adhere to the oil after agitation in water and to float as a scum, while the impurities such as clay and silica are deposited as sediment.

In classifying graphites for the market the first consideration is to obtain a high-carbon percentage, the size of flake also being a very important factor. Fancy grades contain at least 95 per cent. of carbon, high grades contain 90 to 95 per cent., good grades 85 to 90 per cent., medium grades 80 to 85 per cent., and inferior grades 70 to 80 per cent., while grades below 70 per cent. are said to be poor and have a low commercial value. Each grade of quality is re-graded for size of flake or grain, the sizes being known as large lumps, ordinary lumps, chips, dust, and flying dust, so that quite a number of grades are put on to the market.

Regarding the concentration of graphite an article issued by the Toronto University\* on the subject outlines the following

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\* Preliminary Report of an Investigation into the Concentration of Graphite, &c. Can. Min. Jour., vol. 40, 1919, pp. 189-197. Toronto Univ. Dept. of Min. Eng.

as a process:—(1) Crush wet in ball mill with an excess of water and a minimum of crushing; (2) Remove large flakes on over-size screens; (3) Divide into several grades by settlers; (4) Separate each grade into concentrates, middlings, and waste by oil flotation; (5) Separately regrind concentrates and middlings in excess of water; (6) Make high grade flake and a residue which is to be returned for flotation. The advantages are said to be:—(1) Whole process is wet; (2) Minimum destruction of the large flake; (3) Removal of high grade flake not requiring regrinding; (4) Produces a thicker and more brilliant flake than in the dry grinding processes; (5) Process is simple.

The Madagascar graphite deposits are easily mined with spades. The first treatment is by water in sluice boxes to separate coarse flake, after which the finer material containing sand, clay, and graphite is dried, vanned, and screened.

In a paper on the Preparation of Crucible Graphite\* the various concentrating processes are described in detail. The different methods are illustrated by flow sheets of typical mills and by a number of sketches, and comparisons made of their efficiency. Chemical and mechanical analyses of the finished products are given, and recommendations made for the standardization of No. 1 flake and for improved methods of sampling (Ferguson).

Refining Alabama Flake Graphite for Crucible use is the title of an article by F. G. Moses† giving the results of experiments in raising low-grade concentrates to a 90 per cent. grade. Tests were made with an aspirator, pneumatic jig, pebble mill, electrostatic separator, and burr mill, and with oil flotation. The subject is treated under the following headings:—Existing refining methods; Tests with pneumatic jig; Air jig produces clean tailings; Separation of sand and carbon; Tests with electrostatic separator; Summary of results with electrostatic separator; Flotation as a finishing process; The burr mill, its place in graphite finishing; General summary and discussion of results.

Concerning the classification of graphite C. Spearman‡ proposes that No. 1 Flake should be above 90-mesh in size, of which half ought to remain on a 50-mesh standard screen, and that it should contain 85 to 90 per cent. of graphitic carbon.

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\* Preparation of Crucible Graphite. By G. D. Dub. Bureau of Mines, War Minerals Investigation. Ser. 8., Dec., 1918. Washington.

† *Loc. cit.* Also in Eng. and Min. Jour., July 12, 1919, pp. 50-54.

‡ The Graphite Industry. By Charles Spearman. Can. Min. Jour. Vol. 40. Feb., 1919, pp. 87-88.

No. 2 Flake should rest on a 120-mesh screen after passing a 90-mesh screen.

The chemical constituents of graphite, of which several examples are given in Table 62, page 215, are useful to know in determining values for economic purposes but the information is not complete without some data regarding the character of the grain or flake. A graphite might be very good in quality yet of very little commercial value because of its extreme fineness. The following scheme (after Jack *fil.*) provides for a mechanical as well as a chemical analysis of the ore, and on the results obtained by it an estimate can be formed of the capacity required for each portion of the plant in a working proposition:—

#### SCHEME FOR GRAPHITE DETERMINATION.

(For Prospecting Samples.)

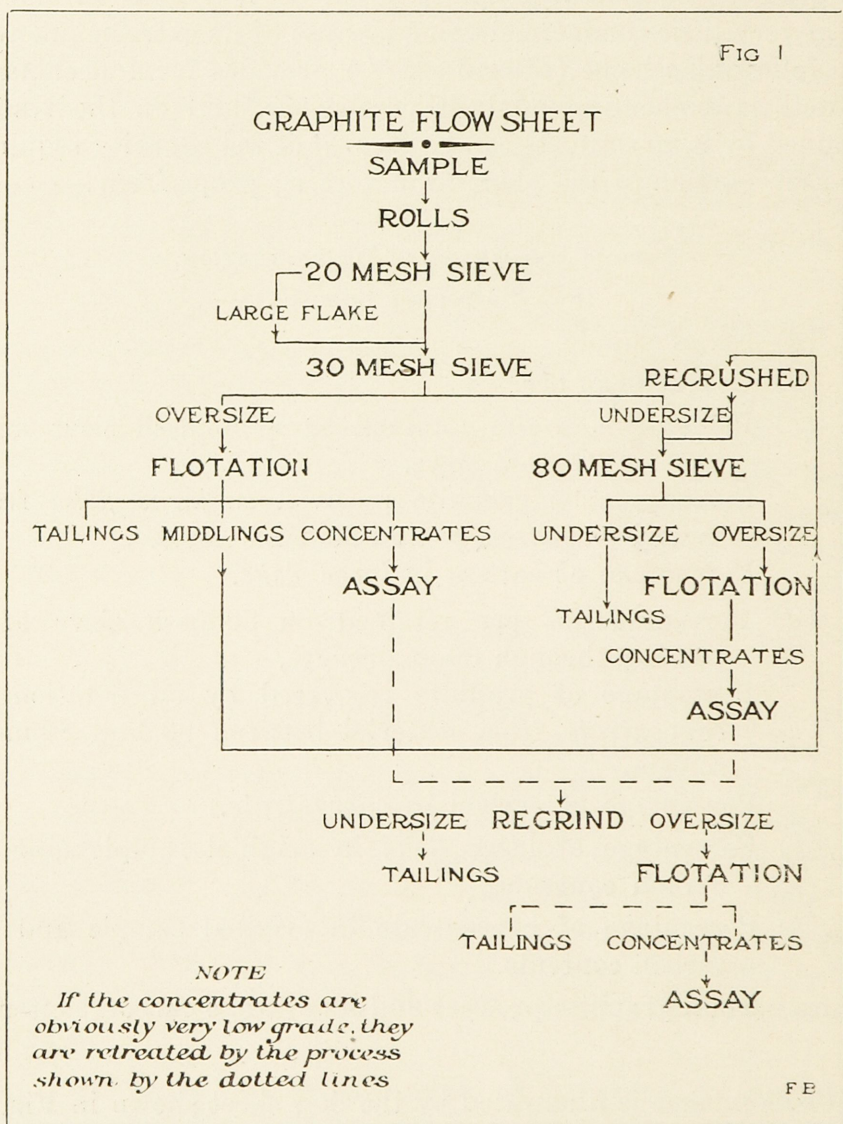
- (a) No. of sample.
- (b) Character of ore.
- (c) Percentage of ore retained on a 30-mesh sieve after passing 20-mesh sieve.  
     Percentage of graphite received as *large flake* from material between 20 and 30-mesh sieves.  
     Percentage of carbon in *large flake*.
- (d) Percentage of ore retained on 80-mesh sieve after passing through 30-mesh sieve.  
     Percentage of graphite recovered by oil flotation as *concentrate* from material between 30 and 80-mesh screens.  
     Percentage of carbon in *concentrate*.
- (e) Percentage of large flake in original sample and its carbon contents.
- (f) Percentage of concentrate in original sample and its carbon contents.
- (g) Total graphite product and its average carbon contents.

This scheme is illustrated by the flow sheet shown in Fig. 1, in which provision is made for a second treatment of the concentrates if they prove to be too low in grade on assay.

In the concentration of graphite on a working scale quite a number of mills are described by H. S. Spence in his Report on Graphite, issued by the Canadian Department of Mines\* all

\* Graphite. By H. S. Spence. Mines Branch, Can. Dept. of Mines, Ottawa. 1920, pp. 202. With 55 photos, 43 drawings and 6 maps.

showing varying conditions, and each accompanied by a flow sheet diagram showing details of the various operations in both dry and wet methods. Jigs, air classifiers, rolls, screens, electrostatic machines, buddles, tables, log washers, rake washers, frothing (oil) flotation and film (water) flotation are described and in some cases illustrated.



In the determination of the carbon content of graded graphite and graphitic ores Spence\* states that "the exact method, or combination of methods, to be followed is largely dependent on the class of material investigated. For instance, to determine the carbon content of a high-grade sample that can

\* Loc. cit. pp. 188-194.

be seen to consist for the greater part of graphite, requires a different procedure to that where a graphite ore of relatively low carbon content is in question. The determination of graphitic carbon with scientific exactness is a matter of difficulty, and, perhaps, cannot be accomplished satisfactorily by ordinary methods. For practical purposes, however, such accuracy is not required, and entirely adequate results are obtained by any one of the several methods ordinarily employed in commercial practice."

The *combustion method* he describes provides for the estimation of hygroscopic moisture, combined water, carbonate of lime and mineral sulphides, any silica and silicates remaining in the ash after combustion. The *fusion method* with caustic potash for graphitic ores is considered to give lower results than the combustion method although it has compensating advantages in other respects, while the *absorption method* of igniting in a stream of oxygen is also good both for ores and for commercial samples. In the *re-carbonating method* the sample is ignited, and after complete combustion the allowance to be made for any carbonates present is determined by treating the ash with ammonium carbonate and drying and heating.

Further notes are given on qualitative and quantitative analyses both in rough estimations and in delicate determinations, also notes on detecting other forms of carbon present with the graphite.

### Percentages of Graphite in Ores.

In Canada the ore in the Buckingham mines yields from 10 to 30 per cent. of graphite, and one of the beds, 20 ft. thick, averages 20 per cent. of graphite, the best product after treatment containing about 97 per cent.

In Madagascar the grades are 20, 40, and 60-mesh, and 60 per cent. of the graphite recovered is of crucible grade. The percentage of graphite in the raw material is variously estimated to be between 25 and 60, and of these qualities there are said to be 2,000,000 tons in sight, with larger quantities of lower grades also present, and 10 per cent. of graphite in the ore is considered payable.

The Mexican amorphous graphite is variable in its carbon percentages, the best product containing about 87 per cent., with occasional patches of very pure ore containing 95 per cent.

Chosen (Korea) amorphous graphite varies between 80 to 85 per cent. carbon, this being the grade of the exported material.

The Ticonderoga mines of New York yield an ore which is stated to contain no more than 6 per cent. of graphite, but which produces the best grade of graphite, that is, 98.8 per cent. pure, while the Black Donald mine at Renfrew, Canada, yields an ore averaging over 30 per cent. of graphite, the high grade product containing 45 per cent. of amorphous graphite, 20 per cent. of crystalline or flake graphite, and 35 per cent. of limestone and chlorite. Low-grade ore in this mine averages 25 per cent., while below 15 per cent the ore is considered too low grade to pay for working.

One mine in Alabama treated a rock containing 3.8 per cent. of graphite, the concentrated product yielding 36 per cent. of flake suitable for crucibles, 29 per cent. of coarse and fine flake for lubrication, and 35 per cent. for foundry facings.

Ceylon vein graphite as it leaves the mines contains 50 per cent. of impurities, while after treatment the finest product contains 99.5 per cent. carbon, the general commercial article, however, being about 68 per cent. pure.

In Passau, Bavaria, the ore in one mine carries from 31 to 53 per cent. of graphite, the best refined product containing 89 per cent., and the tailings from 15 to 20 per cent. Some of the German mines yield a high quality graphite, but in concentrating the product they are only able to save 50 per cent. of the total graphite contents.

The Eyre Peninsula deposits of South Australia vary considerably in the percentages of graphite. About 12 per cent. appears to be the maximum, which indicates favourable conditions so far as graphite is concerned, but the quality of the graphite is low, and 51 per cent. is the highest percentage of carbon contents that has been obtained.

### **Chemical Removal of Graphite Impurities.**

Most of the impurities in graphite have to be removed if refractoriness is an essential quality, otherwise articles made of the material will fuse or become softened at high temperatures, a very undesirable feature in crucibles and electrodes. Silica is not so detrimental as iron oxides, and crucibles are made of graphite containing a high percentage of this ingredient provided the graphite is of the flake variety and other impurities are absent or only present in very small quantities.

Some graphites when heated with nitric and sulphuric acids or with chlorate of potash and sulphuric acid become swollen and flocculent, during which operation most of the impurities

dissolve, and subsequently may be removed by washing with water. Flake graphites which swell up with nitric acid in this way are called “graphites” and those which do not so behave are called “graphitites.”

Hydrochloric acid is used for the removal of several of the impurities, and the hydrate, fluoride or carbonate of soda is used in the removal of silica or silicates from those graphites more particularly required in the manufacture of pencils and lubricants. Oxides of iron are removed by sufficiently heating the graphite to reduce them to metal, then dissolving out the iron with acids. Other chemical processes have been introduced for the removal of impurities but they are principally modifications of the processes outlined above.

Many factors have to be considered in determining whether it would pay to improve graphite by chemical methods, and although it is considered that 40 or 50 per cent. of impurities would not be profitable to remove under any circumstances, the elimination of small amounts consuming very little acid or flux to make a first-class graphite might become profitable.

### Uses of Graphite.

Most of the uses to which graphite is applied depend on one or more of the properties it possesses of being a good conductor of electricity and heat, of forming a protecting cover to metal or wood when mixed with oil or other medium, of marking paper when rubbed on it, of minimising friction when placed in metal bearings, and in being refractory at high temperatures.

Its numerous applications are included in the manufacture of crucibles, phosphorizers, stirrers, foundry facings, stove polish, gunpowder polish, lubricants, pencils, paints, electrodes, commutator brushes, joint packing, graphite cement, and in electroplating processes and boiler scale prevention. These uses absorb varying quantities of graphite, and a number of estimates have been published showing the proportion required for each, of which the following appears to be the best:—

TABLE 63.—GRAPHITE CONSUMED IN MANUFACTURES.

Articles, &c.	Percentages.	Articles, &c.	Percentages.
Crucibles .. ..	65	Polishing powder and shot	2
Stove polish .. ..	10	Graphite paints ..	$\frac{1}{2}$
Facings .. ..	8	Electrotyping .. ..	$\frac{1}{4}$
Lubricants (dry) ..	6	Other uses .. ..	$\frac{1}{4}$
Graphite greases and oils	3		
Pencils .. ..	3		
Joint packing .. ..	2	Total ..	100

Table 63 shows that about two-thirds of the whole of the graphite production of the world is required in the manufacture of crucibles. As the very highest quality of graphite is necessary for this purpose and for which the highest prices are paid, the utilisation of graphite for all other requirements becomes of subsidiary importance. Sometimes, however, the impurities in unrefined graphite happen to be equivalent to the ingredients added to make up the mixture for crucibles or other articles, and under such circumstances graphites containing a high percentage of impurities can be utilised. An example of this is the material used in making the celebrated Passau crucibles in Bavaria, which is made from the graphite and its matrix without in any way being refined.

*Crucibles.*—The graphite used in making crucibles is generally hand-picked, ground, dressed, and mixed with clay and water, any oxide of iron present being removed by sulphuric acid previous to mixing. The moulding is carried out on a potter's wheel or on a rotating machine which mechanically works the graphite into a mould of plaster of Paris. The crucibles after drying are baked in sealed ovens, and every care is taken to raise the temperature by gradual stages, otherwise the pots will crack or some flaw develop which will only become apparent when being used afterwards. The composition of some of the crucible graphites is given in Table 64.

Flake graphite with or without some amorphous graphite forms part of the crucible mixture, the special object of using the flake being to bind together the other ingredients. Crucibles are also made without flake graphite but they are not strong enough to be made into the large sizes required for melting metals, although otherwise useful in work needing only small charges of metal. Excess of clay gives greater strength to a crucible used at low temperature, but makes it soft and fusible when the heat is very high, while any oxide of iron present will be reduced to metal by graphite and thus considerably weaken a crucible—even when only in small quantities.

TABLE 64.—COMPOSITION OF GRAPHITE CRUCIBLES.

—				1.	2.	3.	4.
				%	%	%	%
Moisture	..	..	..	1·8	2·5	2·0	2·0
Silica	..	..	..	51·4	45·1	50·0	31·2
Alumina	..	..	..	22·0	16·7	20·0	12·2
Ferric oxide	..	..	..	3·5	1·1	1·5	2·0
Graphite	..	..	..	20·0	34·5	25·5	52·6
Lime	..	..	..	0·2	?	0·5	Trace
Loss	..	..	..	1·1	1·3	0·5	..

Ticonderoga crucibles are made of 32 per cent. of clay, 18 per cent. of silica, and 50 per cent. of mixed flake and fine-grained graphite, another composition being 45 per cent. of clay, 5 per cent. of silica, and 50 per cent. of graphite. A flake graphite passing a 40-mesh sieve is considered the best, a coarser grain weakening the crucible and a finer grain making it liable to crack. Sometimes the crucibles are washed with clay water containing a slightly fusible ingredient such as borax, and are then glazed and afterwards coated with tar, this treatment preventing absorption of moisture, &c., and enabling the crucibles to better withstand rapid changes of temperature. Fused bauxite and zirconia, two very refractory minerals, have recently been added to the list of substances entering into the composition of graphite crucibles.

The composition of clays used in bonding the graphite in crucibles is a matter for careful study, but the physical characters of the clays are of primary importance. They require to be strong, refractory, plastic, and resistant to fusible metals, and at the same time capable of withstanding fracture during rapid changes of temperature. Notes on the composition and manufacture of crucibles for steel making and other purposes are given by Spence\* in the recent report on Graphite.

One of the Mount Bopple graphite analyses corresponds very closely with the No. 2 analysis in Table 64, and experiments have shown that while it contains none of the flake variety there is no doubt about its refractoriness.

All graphite crucibles, of whatever composition, must be carefully annealed before using, but once used will withstand all rapid changes of heat and cold without any damage.

Graphite crucibles are used for a variety of purposes, specially in the manufacture of steel from iron, but also in the melting of brass and other alloys, in the refining of gold and silver, and in the tempering of files.

*Stove Polish.*—The graphite used for this purpose may be either flake or amorphous, or a mixture of both, and requires to be sufficiently fine to pass through a 120 to 160-mesh sieve. It is marketed as a dry powder or made into a water paste with a soap or gelatinous bond or carrier, or into a spirit paste with methylated spirit and a small quantity of shellac, or an oil paste with turpentine, benzine, &c. The flake variety produces a steel-grey polish with a bright lustre, and the amorphous variety gives a bluish-black polish. Sometimes the two varieties are

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\* *Loc. cit.*, pp. 125-148.

blended to give the blue-black colour of the amorphous variety and the brighter lustre of the flake variety.

The Bopple graphite, ground to 120 mesh and simply moistened with a methylated spirit and shellac varnish, produces a polish on iron when rubbed quite equal to that made by some of the imported brands of stove polish.

*Lubricants.*—Flake graphite is used as a lubricant in many forms, being effective if applied in a dry state or mixed either with oil, grease or water, or with grease and oil, or with grease and finely-ground cedar. Its function when used dry is to form a coating or film on two metal surfaces in contact, one being in motion, and also to fill all surface irregularities which might exist in either. The coating so formed, whether thin or thick, becomes very hard, compact and greasy, and the friction is reduced considerably.

Mixed with oil the best lubricating effect is produced if the graphite is first thoroughly blended with a small quantity of one class of oil, and this to be worked into another oil with which it will not assimilate, the object in view being the prevention of the graphite from settling to the bottom of one oil by keeping it mixed up in the other. Graphite is used with light oil, and if added to inferior oils improves their quality.

Graphite mixed with grease for lubrication has many advantages, particularly with heavy bearings. One of the compositions is made of varying proportions of tallow and graphite, another consisting of 36 parts of tallow, 9 of grease, 9 of palm oil, and 2 of graphite (Cirkel).

Some experiments in the use of graphite mixed with kerosene, light oils, heavy oils, vaseline or grease have shown that with the addition of from 4 to 6 per cent. of graphite a marked improvement is effected in the reduction of friction.

Mixed with water or soapsuds the graphite may be introduced with good effects into bearings which cannot be served with dry graphite, but if machinery is lying idle an inclination exists to form rust in the bearing which does not take place if oil is used. Metal bearings are sometimes made with graphite worked into them when being cast, the object being to make the bearings partly or wholly self-lubricating and to prevent over heating.

Substitutes for graphite as a lubricant are to be found in mica and talc of high quality, either of which gives a good body when mixed with oil, although not equal to graphite in lubricating value.

Experiments have not been tried with Mount Bopple graphite to determine its suitability for lubricating purposes, but all clay and silica impurities would require to be removed, chemically or otherwise, before any trials could be made, and even then probably it would be found to be of no value. Mexican graphite, however, is used considerably for lubricating purposes.

*Foundry Facings.*—Amorphous or fine-flake graphite is used in facing the moulds used in iron and brass foundry work, different operations requiring facings of different qualities. The graphite primarily keeps the metal in the moulds free from the sand which is inclined to adhere to it, and also gives the castings a much smoother surface. It is contended that the molten iron or other metal produces slight combustion in the graphite, and that the carbon monoxide gas thus formed acts as a parting between the mould and the casting, from which it is assumed that a facing is defective if it is not also slightly combustible.

For foundry facings the graphite is usually mixed with finely ground anthracite coal or gas-retort carbon and with a binding ingredient such as clay or tale. The analysis of an imported foundry facing, given in Table 62, shows the presence of about 60 per cent. of impurity, and corresponds very closely with one of the analyses of the Mount Bopple graphites, also given in Table 62. In the latter case, however, the impurities appear to be injurious or the carbon is not completely graphitized, as in testing its quality the graphite was found to give a dull non-metallic colour to the casting, although giving a much smoother surface than that produced by the imported article. Recently a firm has been manufacturing a foundry facing from Mount Bopple graphite, but it has to be subjected to a preliminary treatment before use which has the effect of removing the objectionable features and creating a demand for it.

*Graphite Paints.*—Powdered amorphous or flake graphite, resulting from very fine sieving or air-separating, makes a good protecting paint for iron and steel, if mixed with boiled oil, and is generally considered to be a very much better covering for metals than any other paint compositions. Paint of good quality containing flake or amorphous graphite mixed with the best boiled linseed oil forms a good covering that resists the formation of rust, but inferior paints are on the market which have very little utility in not containing any true graphite.

The special object of a graphite paint is, of course, to prevent oxidation of the metals, and every care is required to remove impurities before the paint is applied, otherwise bad effects will

develop later on. Recently some experiments have shown that iron and steel should have a preliminary coating of a paint or varnish which does not contain graphite, otherwise a galvanic action is set up which encourages the formation of rust, so a non-graphitic carbon composition is recommended as a first coating and a graphite paint as a second coating, the composition of the latter being 30 or 35 per cent. graphite mixed with an equal amount of silica or other ground rock and about 30 per cent. of boiled linseed oil. For resisting weather, city fumes, and heat this paint is considered to be far superior than any other made of iron and lead oxides.

In the oil-painting of woodwork graphite may be used as the sole pigment to produce a very dark grey colour, but it is frequently mixed with other pigments to produce black and very dark shades of green, brown and red.

Graphite paints have great covering power, and consequently produce a rather thin coating unless mixed with silica or iron, lead and zinc compounds. The smoothness of graphite paint is considered objectionable if another coat has to be applied later on, a defect which can be remedied by mixing with it silica, carbonate of lime, or iron oxides.

A trial of the Mount Bopple graphite mixed with boiled oil showed that it produces a fine dark grey colour, has a good covering power, dries quickly, and compares very favourably in these respects with some of the graphite paints on the market.

*Pencils.*—The graphite used for making “black lead” pencils is usually, although not invariably, the “amorphous” variety, which has to be very finely ground and mixed with clay and other substances such as lampblack, sulphide of antimony, tallow, wax, alum, lead acetate and sulphate of soda. Some of these, however, are only introduced for special purposes, or to alter the character of the graphite used, or otherwise to improve the methods of manufacture.

The common constituents of pencils consist of 2 parts of graphite and 3 of clay, these proportions being increased or reduced according to circumstances. The composition used by one manufacturer is 18 parts of graphite, 9 parts of clay, 4 parts of sulphide of antimony and 1 part of lampblack, while another is made up of 2 of graphite,  $5\frac{1}{2}$  of clay,  $1\frac{1}{4}$  of a precipitate formed by adding caustic soda to an alum solution and  $2\frac{1}{2}$  of a precipitate formed by adding metallic zinc to a solution of lead acetate, a third composition containing 3 of graphite, 4 of clay and 1 of sulphide of antimony.

The material is worked up like a pottery clay, pressed into the required shapes by machinery, carefully dried in ovens and then heated in crucible furnaces. Careful although simple experiments have to be made to determine the proportions of the graphite and other ingredients to be used, and also the heating required to give the desired hardness, and finally to boil the rods in wax or tallow, if it is found necessary to remove harshness or to induce toughness. The grinding, moulding, baking, boiling, encasing in wood, varnishing and stamping of the pencils are operations mostly performed by girls, a number of automatic machines also being used in the numerous processes.

The Mount Bopple graphite has been experimented with to determine its pencil-making qualities, and after a number of trials with various mixtures it was found that the natural graphite with its impurities, after fine-grinding, moulding and baking was quite equal in every way to the pencils in common use. The results were very satisfactory and indicated a line of investigation for a valuable utilisation of the material.

*Electrical Uses.*—Graphite is commonly made into electrodes for use in the electro-metallurgical smelting of copper and iron ores, in the manufacture of caustic soda, the production of metals from chloride solutions, and the making of ferro-manganese and other ferro-alloys.

Dry batteries are made of a composition which includes graphite and manganese dioxide, the high electrical conductivity of graphite making it very suitable for this purpose. Spence\* states that the filling mixture in well-known types of dry-cells is made up of 10 lb. of manganese dioxide, 10 lb. of graphite or carbon (or both), 2 lb. of sal-ammoniac, and 1 lb. of zinc chloride. He also mentions that "much of the variation found in dry batteries is due to varying qualities of the carbon used in the filler, . . . and that the more recent improvements are undoubtedly due largely to the liberal use of this highly conductive, though more costly form [graphite] of carbon," but it may also be added that the quality of the manganese dioxide used is also an important factor.

The electroplating of non-metallic substances with metals, specially copper, is an operation readily performed if the substances are previously brushed over or rubbed with finely powdered graphite whose electrical conductivity makes it useful as a base for the electro-deposition of a metal.

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\* *Loc. cit.*, p. 150.

In making the blocks used in printing postage stamps sometimes a mould is made of a mixture of beeswax, turpentine, and graphite, which is afterwards dusted or brushed with fine graphite powder and then plated with copper.

Commutator blocks are also made of fine graphite, or graphite mixed with coke, and with or without the addition of powdered metallic copper, a desirable schistose structure being induced by moulding them under very high pressure, after which they are baked at a high temperature for several hours. The material used for this purpose must be of good quality, particularly in its freedom from any gritty substance and in having good electrical conductivity, and Mexican and other "amorphous" graphites are used for the purpose after being sorted and cleaned.

*Boiler Scale Prevention.*—If the feed water of a boiler is charged with floating particles of graphite in many cases boiler scale will be removed or prevented from forming. It is considered that where the scale has already formed on the iron its attachment is destroyed by the graphite, the action being mechanical and not chemical. One graphite manufacturer advocates the introduction of a pint of graphite in the feed water daily to each 100 h.p. boiler capacity, which amounts to about 3 oz. to each 1,000 galls. evaporated. Conditions will indicate whether this amount should be varied, or whether the graphite is actually of any use, but no doubt in some cases it has proved very effective.

*Graphite Cement.*—For repairing cracked parts of stoves, filling irregularities in metal castings, or joints in iron pipes, a cement is made consisting of 20 parts of graphite, 20 parts of sulphate of barium (barytes), 10 parts of grog (ground fire-brick), 10 parts of lime, and 1 part of varnish. Instead of fire-brick linings for ranges and stoves it has been suggested that graphite made up into composite brick with clay or other bond would be much superior, although some doubt might be raised as to its success for this purpose.

*Other Uses.*—Gunpowder is polished by rotating in a barrel or tumbler the powder grains mixed with graphite, the special object being to coat the particles with a film of graphite to prevent their absorption of moisture. Shot is also polished in the same way to produce a finish. Rubber is sometimes loaded with graphite, and asbestos is mixed with graphite in the manufacture of steam packing, while it forms a useful pigment in the manufacture of grey and black paper. Other uses are found

for it in the manufacture of printer's inks and as an ingredient in magnesite bricks, the effect in the latter case being to increase their heat conductivity.

### Artificial Graphite.

When iron ore is smelted in a furnace with coke, nearly all of the iron is reduced to metal, the other portion being formed into a carbide of iron. After being tapped from the furnace the resulting pig iron is cooled, and as this slowly takes place the carbide parts with some of its carbon in the form of graphite which forms scaly crystals in the main mass of the iron. The graphite can be separated by dissolving the iron in acids or by allowing it to remain in some mineral water, as in the case mentioned previously, or by subjecting it to the intense heat of an electric furnace, which drives off as vapour the iron and most of the other substances with it but leaves the graphite behind.

In the artificial production of graphite on a commercial scale a charge of carbon, preferably anthracite, is mixed with oxide or sulphate of iron or with silica or alumina and heated in an electric furnace to form a carbide of iron, silica, or alumina. The carbide on further heating is decomposed and the iron and other volatile substances are driven off as vapour, while the graphite remains behind as the desired product. In practice a charge is heaped around the electrodes in a furnace, and as the graphite is formed it is withdrawn at the bottom as a fresh charge is placed on top. In the manufacture of electrodes of various shapes and sizes a mixture of petroleum coke, pitch, and a carbide-forming substance is made into the shapes required and then "graphitized" in the furnace. The manufacture of artificial graphite presents no very great technical difficulties but the power required to produce 500 lb. of this material is 37,500 amperes of a 12-volt current, the electrodes being 20 in. apart and having a cross-section of about 3 ft. square. To compete with the natural product the power must be very cheap, and in some parts of the world this has been obtained by the hydrostatic pressure from waterfalls. Artificial graphite is said to be better adapted to electrical work than natural graphite and is able to compete with it in many industries, although for crucibles of good quality it is useless because it cannot be made into the flake variety necessary in their manufacture.

In the Report on graphite by Spence\* some details of the manufacture of artificial graphite are given, including a description and sketches of the electric furnaces used in the operations.

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\* *Loc. cit.*, pp. 114-118.

### Graphite Production.

The total yields and values from countries given in Table 65 show very clearly that Ceylon is the premier graphite producer of the world. Austria has yielded altogether about half as much more graphite than Ceylon, the total value of the Ceylon production, however, being more than six times that of Austria, while the high quality of the former is such that the general average value per ton is more than eight times that of the Austrian production.

The United States is the third largest producer, and if the value of her artificial graphite production is included with that of the natural article her yield is more valuable than that of Austria.

Madagascar only became a producer in recent years yet her total yield is probably equal to that of Germany at the present time, although much below that of Ceylon, United States, and Austria; but the value of her production is increasing enormously. Next in order of production come Italy, Mexico, Japan, India, and Canada, of which Canada's yield is the highest in value.

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TABLE 65.—TOTAL GRAPHITE PRODUCTION BY COUNTRIES, TO 1918.

*(Compiled from various sources.)*

Country.	Years.	Production.	Value.	Value per Ton.		
		Tons.	£	£	s.	d.
Ceylon .. ..	1880-1918	877,900	17,439,966	19	17	3
Austria .. ..	1856-1913	1,148,040	2,652,170	2	6	2
United States—						
Amorphous .. ..	<i>a</i> 1880-1918	131,239	} 2,643,360	13	15	6
Refined .. ..	1880-1918	60,655				
Artificial .. ..	1892-1918	60,597	..	..		
Madagascar .. ..	1907-1918	108,861	1,854,766	17	0	9
Germany .. ..	1862-1913	174,952	474,245	2	14	3
Japan .. ..	1881-1917	33,660	<i>c</i> 360,717	10	14	4
Italy .. ..	1860-1917	262,942	318,525	1	4	3
Canada—						
Refined .. ..	1886-1918	30,981	393,515	12	14	0
Artificial .. ..	1906-1918	7,169	..	..		
Korea (Chosen) .. ..	<i>b</i> 1908-1917	..	<i>c</i> 212,269	..		
Mexico .. ..	<i>b</i> 1893-1918	58,799	<i>c</i> 346,548	5	17	10
India .. ..	1898-1917	40,309	187,577	4	12	0
South Africa .. ..	1910-1917	345	11,397	33	0	8
Sweden .. ..	1861-1917	6,465	<i>c</i> 14,528	2	4	11
Russia .. ..	1891-1909	691	9,704	14	0	0
Norway .. ..	<i>b</i> 1906-1912	5,359	9,114	1	14	0
France .. ..	1902-1913	3,424	4,296	1	5	1
Spain .. ..	1890-1917	3,516	985	0	5	7
United Kingdom .. ..	1895-1908	141	201	1	8	6
New South Wales .. ..	1894-1917	741	6,950	9	7	7
Queensland .. ..	1905-1908	148	732	4	19	0

*a* Between 1906 and 1915 the production of amorphous graphite amounted to 52,614 tons, valued at £110,633, equal to £2 1s. 3d. per ton.

*b* Exports.

*c* In part estimated.

TABLE 66.—ANNUAL GRAPHITE PRODUCTION OF PRINCIPAL COUNTRIES, 1913-1918.

(Compiled from various sources.)

	YEARS.					
	1913.	1914.	1915.	1916.	1917.	1918.
<i>Ceylon d</i> .. .. Tons	25,482	14,234	21,822	33,419	27,136	15,453
Total value £	611,568	238,000	535,298	1,520,439	1,473,292	559,375
Value per ton £	24 7 10	16 14 5	24 10 7	45 9 11	54 9 5	36 4 0
<i>United States—</i>						
Amorphous .. .. Tons	2,003	1,540	1,055	2,341	7,412	5,858
Total value £	8,214	8,073	2,575	4,317	15,308	14,470
Value per ton £	4 2 0	5 4 10	2 8 10	1 16 11	2 1 4	2 9 5
Refined .. .. Tons	2,261	2,331	3,158	4,880	6,250	5,742
Total value £	52,985	59,452	86,932	190,572	228,000	303,083
Value per ton £	23 8 8	25 10 1	27 10 6	39 1 0	36 9 7	52 15 8
Artificial .. .. Tons	6,086	4,667	2,269	<i>b</i> 3,704	<i>b</i> 4,676	<i>b</i> 4,099
Total value £	202,791	145,583	20,756	..	..	..
Value per ton £	33 6 5	31 2 5	9 2 11	..	..	..
<i>Madagascar</i> .. .. Tons	6,219	7,873	14,763	25,077	34,447	15,747
Total value £	87,066	110,200	206,700	461,041	633,333	<i>a</i> 290,000
Value per ton £	14 0 0	14 0 0	14 0 0	18 7 8	18 7 8	18 7 8
<i>Italy</i> .. .. Tons	10,970	8,432	6,078	3,131	11,925	..
Total value £	13,429	10,323	8,354	12,156	29,563	..
Value per ton £	1 4 6	1 4 6	1 7 6	3 17 8	2 9 7	..
<i>Canada---</i>						
Refined .. .. Tons	1,573	1,475	2,353	3,571	3,316	2,780
Total value £	18,309	22,334	25,880	67,784	83,936	51,848
Value per ton £	11 12 9	15 2 10	11 0 0	18 19 8	25 6 3	18 13 0
Artificial .. .. Tons	975	551	222	234	489	809
Total value £	32,500	17,100	2,000	..	..	..
Value per ton £	33 6 5	31 2 5	9 2 11	..	..	..
<i>Chosen (Korea) c</i> .. Tons	10,208	10,826	6,934	16,680	6,397	..
Total value £	24,100	29,750	21,052	50,625	19,400	..
Value per ton £	2 7 3	2 15 0	3 0 9	3 0 9	3 0 9	..
<i>Mexico</i> .. .. Tons	3,959	3,804	1,501	4,755	6,750	5,000
Total value £	41,250	39,599	15,625	49,583	59,493	27,955
Value per ton £	10 8 5	10 8 2	10 8 2	10 8 6	8 16 0	5 11 10
<i>New South Wales</i> .. Tons	..	..	70	50	70	200
Total value £	..	..	30	25	30	<i>e</i> 6,000
Value per ton £	..	..	..	..	..	30 0 0

(a) Estimated.

(b) Powdered graphite only.

(c) Chosen graphite is mostly exported *via* Japan.

(d) Exports.

(e) From Ann. Rep. of Dept. of Mines, N.S.W., 1918 (1919), p. 62.

TABLE 67.—EXPORTS OF GRAPHITE BY PRINCIPAL PRODUCING COUNTRIES (a), 1913-1918.

Country Exporting.		YEARS.						Country Importing.
		1913.	1914.	1915.	1916.	1917.	1918.	
<i>Ceylon</i>	.. Tons	15,175	7,930	12,938	23,421	21,942	8,060	United States
	Value £	348,909	202,585	380,466	1,324,278	1,495,668	499,528	
	Tons	5,988	2,623	5,671	5,219	4,034	6,385	United Kingdom
	Value £	165,379	57,879	161,572	367,870	310,783	b 446,900	
	Tons	5,516	3,148	..	..	..	..	Germany
	Value £	b 152,000	b 69,000	..	..	..	..	
	Tons	1,704	865	..	..	..	..	Belgium
	Value £	b 47,000	b 19,000	..	..	..	..	
	Tons	201	318	261	278	236	293	Australia
	Value £	..	..	..	..	..	..	
<i>United States</i>	Tons	2,904	1,751	472	712	2,298	852	
	Value £	51,647	57,788	10,955	20,441	72,826	25,329	
<i>Canada</i>	.. Tons	1,484	1,612	2,674	3,685	3,104	2,754	United States
	Value £	20,555	19,278	24,251	65,454	72,715	49,216	
	Tons	57	167	..	..	..	..	United Kingdom
	Value £	1,216	2,952	..	..	..	..	
<i>Mexico</i>	.. Tons	3,960	3,803	1,500	4,760	6,759	5,000	United States
	Value £	41,250	39,599	15,625	49,583	59,493	27,955	
<i>Japan (cohseh)</i>	Tons	3,723	5,649	2,119	4,800	2,198	507	United States
	Value £	12,125	20,090	7,353	21,589	17,408	5,095	
	Tons	3,860	4,167	3,809	5,435	1,535	..	United Kingdom
	Value £	27,293	29,583	22,380	42,735	12,931	..	
<i>Madagascar</i>	.. Tons	..	311	1,310	1,456	3,922	866	United States
	Value £	..	8,063	38,247	50,388	220,225	55,278	
	Tons	4,035	4,404	4,584	9,310	10,167	..	United Kingdom
	Value £	93,662	95,908	93,930	332,651	390,268	..	
	Tons	..	3,276	7,194	..	..	..	France
	Value £	..	..	..	..	..	..	
<i>Italy</i>	.. Tons	210	227	24	135	103	15	United States
	Value £	846	667	207	861	435	131	
	Tons	1,250	1,123	2,173	2,257	2,151	..	United Kingdom
	Value £	5,613	5,175	10,064	15,623	24,901	..	
<i>India</i>	.. Tons	481	113	84	1,071	233	..	United States and United Kingdom
	Value £	6,588	2,045	3,622	71,494	21,354	..	
<i>Austria</i>	.. Tons	589	70	..	..	..	..	United States
	Value £	2,074	262	..	..	..	..	
	Tons	448	86	..	..	..	..	United Kingdom
	Value £	3,396	764	..	..	..	..	

(a) Compiled from Mineral Resources of the United States and Mineral Production of Canada (Serials).

(b) Estimated.

Table 66 showing the annual graphite production of each country between 1913 and 1918 indicates that Ceylon has consistently produced the largest yields but that Madagascar has enormously increased her output from 6,219 tons in 1913 to 34,447 tons in 1917, the estimated value of the yield for the latter year being £633,333, while Ceylon produced in the same period 27,136 tons with an estimated value of £1,473,292. Austria and Germany before the war were large producers of graphite, but no statistics are available showing what their production has been in recent years.

In 1918, the last year for which records are available, a very great decrease in production took place, the Ceylon and Madagascar yields being about equal, but with the value of the former double that of the latter.

The Mexican and Korean productions are of interest, as the deposits in those localities are similar in character to the Mount Bopple deposits in Queensland.

The exports of graphite from producing countries given in Table 67 are only approximately correct. Mostly the statistics showing the imports by a country do not tally with those given by the country making the exports, but such inconsistencies cannot be remedied.

The only statistics showing imports are those published by the United States, United Kingdom, and Germany, of which the last named is only complete up to the end of 1913.

The United States is the largest user of Ceylon graphite, the United Kingdom taking a much smaller quantity than that required by the former country. France and the United Kingdom now take most of the Madagascar production, the United States requiring very little in comparison. War con-

TABLE 68.—IMPORTS OF GRAPHITE BY PRINCIPAL COUNTRIES (a), 1913-1918.

Country Importing.	YEARS.						Country Exporting.
	1913.	1914.	1915.	1916.	1917.	1918.	
United States Tons	25,785	19,554	20,603	38,830	38,015	17,409	Various
Value £	439,540	291,293	466,909	1,516,642	1,867,090	644,265	
United Kingdom Tons	20,674	14,828	18,396	26,535	20,018	..	Various
Value £	347,606	217,606	347,587	899,226	833,428	..	
Germany .. Tons	36,580	..	..	..	..	..	Ceylon principally
Value £	b 615,000	..	..	..	..	..	

(a) Compiled from Min. Res. U.S.A. and Min.-Ind.

(b) Estimated.

ditions are stimulating the production of graphite in the United States where competition is now developing against the imports from Ceylon and Madagascar.

The exports of Ceylon graphite in 1916, as shown in Table 67, are considerably higher than those of the preceding or succeeding years, the increase being due to war conditions.

The last year for which statistics are available, 1918, shows that a very large reduction took place in the exports of all producing countries, a conspicuous feature being the drop in the exports to the United States from Madagascar.

Before the war Germany was using much more graphite than either the United States or the United Kingdom, her total imports in 1913 being 36,580 tons. Of this quantity 5,516 tons were obtained from Ceylon, and probably most of the Austria-Hungarian exports were received by her, which makes a total amount of 28,524 tons, or 8,060 tons less than her statistics show. In 1914, Ceylon appears to have sent to Germany 3,148 tons but the war stopped the trade.

TABLE 69.—COMMONWEALTH IMPORTS OF GRAPHITE, 1913-1918-9.

State.	1913.	1914-15.	1915-16.	1916-17.	1917-18.	1918-19.
	£	£	£	£	£	£
New South Wales ..	1,872	1,561	1,845	2,112	1 934	3,634
Victoria ... ..	3,727	2,709	4,039	2,448	3,265	2,106
Queensland .. ..	1,369	1,444	1,356	2,095	372	487
South Australia ..	2,077	1,949	2,535	1,343	470	442
Western Australia ..	648	668	2,433	1,086	194	312
Tasmania .. ..	92	26	19	9	..	..
Northern Territory ..	..	2	..	..	..	..
Total ..	9,785	8,359	12,227	9,093	6,235	6,981

Table 68 indicates large increases in the 1916 imports of both the United States and the United Kingdom with very little alteration in 1917, and although no figures are available to show the imports into the United Kingdom during 1918, no doubt there was, as with the United States, a considerable decrease on the 1917 imports. As the graphite is such an essential ingredient in metallurgical operations, the large quantities absorbed by the United States is indicative of the great increase in her manufacturing industries during 1916 and 1917. The Table also shows that the United States requirements were nearly 50 per

cent. greater than those of the United Kingdom during 1916, while her pre-war imports were only about 30 per cent. greater.

Germany before the war was using more graphite than the United States and nearly double that of the United Kingdom, but there are no recent statistics published.

### Graphite Values and Quotations.

Table 69 contains the values of the Commonwealth imports of graphite for a number of years, but the quantities are not recorded.

TABLE 70.—GRAPHITE QUOTATIONS, LONDON, 1913-1915.

Classification.	1913.		1914 and 1915.	
	Value per ton.		Value per ton.	
	£	£	£	£
Crude Ceylon—				
Large lumps .. ..	18	to 41	20	to 40
Ordinary lumps .. ..	13	to 42	15	to 40
Chips .. ..	12	to 32	14	to 31
Dust .. ..	11	to 29	14	to 29
Refined Ceylon—				
97 to 99 per cent. .. ..	59	to 63	59	to 63
90 to 91 per cent. .. ..	40	to 42	40	to 42
80 to 81 per cent. .. ..	30	to 32	30	to 32
70 to 71 per cent. .. ..	27	to 28	27	to 28
American—				
Large flake .. ..	45	to 49	45	to 49
Small flake .. ..	35	to 45	35	to 45
Compositions—				
Joint compo. .. ..	Value per cwt.		Value per cwt.	
Paint paste .. ..	£2 9s. to £2 12s.		£2 9s. to £2 12s.	
	£2 12s. to £2 15s.		£2 12s. to £2 15s.	
	Value per gal.		Value per gal.	
Paint .. ..	6s. 3d. to 6s. 9d.		6s. 3d. to 6s. 9d.	

In Table 66, showing the annual production of the principal countries, the average values of the graphite per ton are also given, from which a general estimate may be formed of the prices paid at port of shipment. The Ceylon figures show prices varying from £24 to £54 in the period 1913-1917, and the Madagascar figures vary from £14 to £18 for the same period. In Table 72 showing export values for these two producing countries the values are consistent with the above and show, at least in the case of Madagascar, that the production values in Table 66 are only an official estimate, and that more reliance can be placed on the value of the production by taking the export values and

making an allowance for transport costs, etc., between locality of production and port of shipment. Madagascar retail prices in London were about £32 per ton for first quality in 1915, £35 in 1916, £45 in 1917, and £40 in 1918.

The Chosen amorphous graphite values of production vary from £2 7s. 3d. to £3 0s. 9d. per ton for the five-year period, and the Mexican from £5 11s. 10d. to £10 8s. 6d., while amorphous American shows a variation from £1 16s. 11d. to £5 4s. 10d. Export values would be an increase on these figures. The New South Wales amorphous graphite in 1918 shows a value of £30 per ton, but the previous year's total production is valued at £30, and there appears to be some confusion regarding *total* value and value *per ton*.

Statistics showing graphite prices in London have not been published regularly and no quotations can be given, but during 1913, 1914, and 1915, the information is complete and is given in Table 70. New York quotations are fairly complete for the years 1914-1920 in the first and second grades, and are given in Table 71.

TABLE 71.—MARKET QUOTATIONS OF CEYLON GRAPHITE IN NEW YORK, 1914-1920.

—	1914.	1915.	1916.	1917.	1918.	1919.	1920.
	Value per ton.	Value per ton.	Value per ton.	Value per ton.	Value per ton.	Value per ton.	Value per ton. £
	£ £	£ £	£ £	£ £	£ £	£ £	
Lump—							
First grade ..	30-44	45-93	93-130	130-149	71-133	67-75	75
Second grade ..	35-40	37-65	65-98	98-107	65-102	64-70	70
Chips—							
First grade ..	34-36	33-65	63-93	93-107	58-100	52-55	55
Second grade ..	30-33	30-55	53-80	80-88	52-86	50-52	52
Dust—							
First grade ..	22-25	35-44	44-55	52-60	50-55	37-42	42
Second grade ..	16-18	30-44	44-47	47-55	42-47	35-37	22

### Graphite Mining Prospects.

Up to the present time no area in Queensland has been discovered where mining for flake graphite can be recommended, although immense areas exist where deposits might ultimately be found.

The granite areas in the Croydon Goldfield have remote possibilities, and a critical examination of the graphitic granites there, particularly about the old workings on the Golden Gate

line of reef, might reveal belts of rock containing a payable percentage of flake. The graphite exposed in the gold workings in the beds of slate on the Gympie Goldfield is of an extensive character although mixed with too much clay to be of any use.

Mount Bopple or its environment appears to offer the best inducements in graphite mining, as the area over which the mineral occurs is very large and numerous seams of it have been exposed, although only the amorphous variety can be expected to be found there.

TABLE 72.—VALUES OF CEYLON AND MADAGASCAR GRAPHITE EXPORTS.  
(To United Kingdom and United States, 1913-1918.)

			<i>Madagascar Exports.</i>		
			Tons.	Value. £	Average Value per ton. £ s. d.
1913	..	..	4,035	93,662	23 4 2
1914	..	..	4,715	103,971	22 1 0
1915	..	..	5,894	132,177	22 8 7
1916	..	..	10,766	383,039	35 11 6
1917	..	..	14,089	610,493	43 6 8
1918	..	..	Not available		
			<i>Ceylon Exports.</i>		
1913	..	..	21,163	514,288	24 6 0
1914	..	..	10,553	260,464	24 13 8
1915	..	..	18,609	542,038	29 2 7
1916	..	..	28,640	1,692,148	59 1 8
1917	..	..	25,976	1,806,450	69 10 10
1918	..	..	14,445	946,428	65 10 5

In prospecting for graphite the flake deposits should be looked for specially in granites, gneisses, schists, pegmatite dykes, and crystalline limestones. Localities where granitic intrusions have metamorphosed coal-bearing rocks should also be examined, but areas of recent volcanic disturbances would be useless to inspect as any coal present would only be formed into a natural coke.

In roughly estimating the importance or value of a graphite deposit a preliminary examination would show whether the flake or amorphous variety is present. This could be confirmed

by crushing a sample on a plate or in a mortar, which reduces amorphous graphite to a dull powder but breaks up the flake form to fine scaly glistening particles, after which further details might be obtained by following out the scheme given on page 221 concerning graphite determination in prospecting samples. Then comes the question of what constitutes a payable percentage and this rests on such factors as distance from markets, cost of production, purity of the product, and prices realisable.

To compete with oversea markets the enormous resources of Ceylon and Madagascar and the low costs of production in those countries would have to be considered. The Madagascar production particularly increased rapidly during the war, but practically ceased in the middle of 1918 on account of shipping troubles, and because the users of the article greatly reduced their purchases. One writer considers there will be great over-production unless steps are taken to minimise outputs.

Taking refined flake graphite averaging 80 per cent. of carbon with variations from 70 to 95 per cent., at £25 per ton, with variations from £20 to £60 per ton, according to size of flake, an opinion may be formed as to the minimum percentages of graphite required in a gangue as a first consideration in determining whether a mining proposition is payable or otherwise. On these English and American pre-war values a yield of, say, 20 per cent. of a graphite containing 80 per cent. of carbon would have an initial value of £5 per ton, or at the rate of 5s. per unit and more than double this value in Australian prices, which would be increased if the quality of the flake were above 80 per cent., or diminished if below that percentage or if mixed with a gangue which makes it unsuitable for concentration by mechanical means. Present prices are much above pre-war prices, although falling, and the payable percentage of graphite in an ore would probably be much lower than the above figures indicate, and any mining proposition would require to be based on the prices given in Tables 70, 71, and 72.

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## Article 8.—MANGANESE.

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### Queensland Localities.

The most important manganese occurrences are in the Gladstone and Rockhampton districts, the mine at Mount Millar near the former town being by far the largest producer of manganese ore in the State. Other localities about Gladstone where similar deposits occur include Auckland Point, Calliope, Targinnie, Turtle Island, Ulam, and Mount Kelly near Bajool, those nearer Rockhampton including Yeppoon, Cooraman, Tungamull, Cawarral, and Malchi.

Near Gympie the Skyring, Nansen, and Cross deposits, in an area about Eel, Pie and Mary Creeks, have been prospected to a small extent, and from the two former several hundreds of tons of ore have been mined. A large area exists in this neighbourhood in which prospecting might reveal large deposits, although at present much of it is covered with dense scrub and is somewhat inaccessible. Near Woolooga Railway Station, at the Devil's Mountain, several large outcrops are reported to occur which are worth prospecting; while at Kandanga, to the south of Gympie, two lodes have recently been discovered, named respectively the Kandanga and Bollier. A third one of very large proportions and known as the Amamoor Lode is being opened up in the same district, and a fourth on Amamoor Range, known as Letheran's, is under investigation.

Other isolated occurrences of manganese lodes are recorded at Mount Perry, Gin Gin, Mount Walli near Kenilworth, Black Snake and other places near Kilkivan, Colosseum near Miriam Vale, Blackbutt, Nanango, Kangaroo Hills, Pine Mountain and Mount Crosby near Ipswich, Beenleigh, Silver Spur, and at several localities to the west and south-west of Warwick, of which the most noted are those at Pikedale, Talgai, The Glen, Thane's Creek, Omanama, Yuraraba, and Inglewood.

### Other Localities.

Within the Commonwealth, besides those mentioned above, important manganese deposits occur at Pernatty Lagoon in

South Australia and at Grenfell and Cookamidgera in New South Wales, but innumerable occurrences are recorded of many other deposits in the above mentioned States and in Victoria. New Zealand has manganese mines at the Bay of Islands, which, however, ceased producing ore years ago; and Western Australia has deposits at Ashburton, Yalgoo, Phillips River, Balladonia, and Peak Hill Goldfield.

The most productive country in the world for manganese ore is Russia, the next most productive being India, then Brazil and Germany. Other localities, in their order of importance (where the ore is being produced) are Spain, United States, France, Chili, Turkey, Austria, Japan (Chosen), Cuba, Belgium, Greece, United Kingdom, Hungary, Sweden, Italy, Bosnia, Herzegovina, Portugal, Canada, Panama, Porto Rica, and New Zealand. Many other countries contain manganese deposits which have not yet been developed, or are of no importance.

### Geological Notes.

Manganese in Queensland occurs principally in ferruginous slates, schists, quartzites, and other sedimentary rocks. About Gladstone and Rockhampton a belt of Devonian serpentine and limestone occurs close to and above a series of these mangani-ferous sedimentary rocks, while a series lower than the latter contain the same class of rocks, perhaps slightly more altered, in which there is a general widespread occurrence of phosphates such as apatite, turquoise, and wavellite. This sequence is so persistent that in a locality where a series occurs one or both of the others are also to be found, conspicuously so in areas in the Rockhampton and Gladstone districts, and about Kilkivan and Ipswich.

At Black Snake near Kilkivan the occurrence has been recorded of a blue-black cobaltiferous wad. The ore is in the form of small irregular masses and nodules in a lode traversing serpentine, and, although high in cobalt and manganese, the quantities available are very small. It is closely associated with a well-defined lode of low-grade garnierite, the nickel silicate. The manganese deposits about Gladstone and at Cawarral to the east of Rockhampton are in a series of slates and quartzites provisionally classed at Silurian, and at Colosseum near Miriam Vale they are in schists which are adjacent to granite and which have been disturbed by diorite. Another belt of large dimensions occur to the west, south-west, and south of Gympie, the rocks also being slates and quartzites, the lodes occasionally trending in a straight course but usually forming irregular masses.

The large lodes of Kandanga and Amamoor, those of Eel, Pie, and Mary Creeks further north, and others further south and at Mount Walli near Kenilworth are all in this series of rocks; and, no doubt, as the scrub country about these localities becomes cleared other manganese lodes will be discovered. The Mount Walli Lode is nearly 60 feet wide in one place, the Kandanga Lode (Sel. 31v; half a mile north from Imbil Railway Station) is 20 feet wide, so far as exposed, the Bollier Lode ( $1\frac{1}{2}$  miles west from Imbil on Sel. 80v) varies between 20 and 40 feet in width, while the Amamoor Lode (5 miles W.S.W. from Amamoor Railway Station to the south of Gympie) is anything over 30 feet wide and has such a large outcrop that it must be considered the largest manganese lode in the State, so far discovered.

To the west of Warwick, and at Inglewood, Yuraraba, and Omanama in Southern Queensland lodes exist in slate and other sedimentary rocks, their age being probably Permo-Carboniferous. The lodes in this district are not of large extent but the quality is fairly good so far as metallic manganese is concerned, and they have a low percentage of silica and iron.

Unimportant manganese deposits are to be observed on the plains of Western Queensland, having the form of hard nodules and narrow bands in sandstones, clay shales, and laterites, a conspicuous occurrence being at Lucknow Woolshed, on Polygammon Creek, a branch of the Hamilton River, about 150 miles W.S.W. of Winton. The character of the formations here suggests the manganese to be a marine deposit in the Upper Cretaceous fossiliferous beds.

Another interesting manganese occurrence is its association with the wolfram lodes of Northern Queensland. Where such lodes have been weathered they sometimes form ironstone outcrops without containing a trace of tungsten and manganese, these somewhat soluble constituents of wolfram being removed by surface waters in the form of oxides. The tungsten remains in solution, but the manganese is precipitated as bog manganese or wad if there happens to be a swamp in the neighbourhood into which the waters drain.

In the gold-bearing rocks at Gympie there are beds of purple manganiferous shale interbedded with black carbonaceous shale and other sediments. Where reefs cross the purple shale the contained quartz is barren, while in the neighbourhood of the black shales the quartz is gold-bearing, the carbon acting as a gold precipitant, the manganese having a counteracting or

oxidizing effect, so that all or nearly all mining operations on this field are primarily based on the search for the carbon—the “plumbago” beds—and the avoidance of the manganese.

The manganese deposits at Pernatty Lagoon, near Woocalla, on the Port Augusta-Kalgoorlie railway line, occur in the form of extensive pockets in the joints of a horizontally bedded ferruginous dolomite, while other large deposits exist in overlying soil. The saline mud and soil of the lagoon somewhat obscure the deposits and prevent an estimate being formed of their extent.

Deposits of manganese in Western Australia are principally developed at the Horseshoe Range mines on the Peak Hill goldfield, on the head waters of the southern branch of the Gascoyne River, in the Geraldton District. The rocks are principally metamorphosed sandstones and phyllites containing hematite and quartz lodes, on which rest sheets of manganese ores, and which have probably been formed as horizontal accumulations of sediment.

In other countries manganese deposits occur in both igneous and sedimentary formations of all ages, and of all kinds, but favour rocks of sedimentary origin. Gneisses, schists, quartzites, shales, limestones, sandstones, and laterites are associated rocks, while quite recent accumulations of sands and soils are known to contain the metal in one form or another and which often form very important deposits.

The principal Brazilian deposits are at Minas Geraes, about 300 miles north of Rio de Janeiro, the occurrences being in rocks of Archæan and pre-Cambrian Age. The manganese in one type of deposit is in irregular lenses in schists or gneisses with granite in the neighbourhood; another type being a defined bed two or three miles long in somewhat metamorphosed rocks; a third type taking the form of lump or irregular masses in clays and soft earth. The ores are mostly psilomelane, but pyrolusite and other manganese-bearing minerals are present.

The Indian deposits, of which there are four different types, are situated principally in the Central Provinces, but others of minor importance occur in Bengal, Bombay, Central India, Madras, and Mysore. In the Central Provinces recent deposits at Rhándára are made up of lateritic concretions, &c. Pre-Palæozoic deposits at Bálághát, Chhindwára and Nagpur are (1) in the form of beds and lenses in slates, quartzites and other metamorphic rocks; (2) in more highly altered rocks, as hornblende and mica schists; and (3) in nodules and lenses in

crystalline limestones. The ore is usually psilomelane, with braunite, “hollandite,”\* rhodonite, and spessartite also present.

Chilian deposits are of Mesozoic Age and occur in three forms, namely—(1) as beds of psilomelane with braunite, sometimes several feet thick, in a limestone-chert formation; (2) as beds of pyrolusite sometimes four feet thick, in sandstones, shales, and limestone with trachytic and other lava flows; and (3) as veins in the volcanic rocks.

Russian deposits in the Caucasus and Nikopol are Cretaceous-Tertiary in age, and have been formed in a series of calcareous and arenaceous sandstones. The ore is principally concretionary and oolitic pyrolusite, although psilomelane and wad is also present, and much of the ore is soft and powdery.

Cuban deposits of manganese are in marine limestones, glauconite sand, and volcanic tuffs, and in some places associated with jaspers of undetermined age. The ore, which is mostly pyrolusite, is of irregular occurrence, sometimes being in the jasper or country rocks in the form of nodules and sometimes as veins in the jasper. The jasper and the manganese ore are considered to be secondary formations in the country rocks.

For the benefit of the prospector looking for manganese deposits in Queensland it may be stated that granite and all other igneous rocks offer very little prospects for the discovery in them of valuable manganese lodes, most of the occurrences being in altered sedimentary rocks, which, however, may be near granite. The serpentines referred to are a guide to the trend of the manganese belts but do not themselves carry manganese except as an impure wad, and then almost invariably in close association with cobalt—and sometimes with nickel.

### Manganese-bearing Minerals.

*Pyrolusite*.—Colour, iron-black to steel-grey, sometimes bluish; lustre, metallic; usually crystalline; brittle. Hardness, 2, 2.5; specific gravity, 4.82. Composition—dioxide of manganese (63 per cent. of manganese and over 18.0 per cent. of available oxygen). The most useful ore of manganese for chemical and electrical purposes, and very useful in steel manufacture.

The occurrence of this mineral has been noted at Chillagoe, Charters Towers, Mount Millar, Auckland Point at Gladstone, Kangaroo Hills, Stanthorpe, Warwick, and other places.

*Psilomelane*.—Colour, iron-black to steel-grey, commonly with a bluish tinge; lustre, sub-metallic; usually massive, not

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\* See Manganese Ore Deposits of India, by L. L. Fermor; pp. 87-97.

crystalline. Hardness, 5 to 6 (much harder than pyrolusite); specific gravity, 3.5 to 4.5. Composition—hydrous dioxide of manganese; contains up to 80 per cent. of dioxide and 60 per cent. of metal, but usually much less; the monoxide, iron oxides and water also being present. Commonly used in steel making, and also for chemical purposes when the percentage of manganese dioxide is high. Available oxygen varies from 7 to 15 per cent.

Its occurrence has been recorded in a vast number of localities about Rockhampton, Gladstone, Gympie, Warwick, and Stanthorpe.

*Manganite*.—Colour, iron-black to steel-grey; lustre, sub-metallic; usually crystalline with striated faces. Hardness, 4; specific gravity, 4.3. Composition—hydrous sesquioxide of manganese (62.4 per cent. of manganese with about 10 per cent. of water and 9 per cent. of available oxygen). Of no use in chemical or electrical operations, but makes the best ferro-manganese. Its occurrence at Cloncurry and Blackbutt has been recorded.

*Wad* (Bog Manganese).—Colour, dull-brownish or bluish-black; usually friable and earthy and soils the fingers when rubbed. Specific gravity, 3 to 4.2. Composition—indefinite, generally consists of oxides of manganese and iron, with silica, baryta, and alumina. Sometimes contains 80 per cent. of manganese dioxide, and generally with a high percentage of water. *Lampadite* is a copper-manganese wad; *Asbolite* is a cobalt-manganese wad.

The mineral is not an important ore for manganese, but sometimes occurs in large quantities, and is then utilised if the quality is high.

It is found in several places in Queensland, but not in quantities sufficiently large to be of commercial value. At Black Snake near Kilkivan it is associated with cobalt, and in the Chillagoe and Herberton Districts it forms secondary deposits from the denudation of wolfram lodes.

*Braunite*.—Colour and streak, generally brownish-black. Hardness, 6; specific gravity, 4.8. Composition—a sesquioxide of manganese with a small amount of silicate; contains about 62 per cent. of manganese, and about 8 per cent. of available oxygen.

*Hausmanite*.—Colour, brownish-black; streak, chestnut brown. Hardness, 5; specific gravity, 4.8. Composition—a monoxide and sesquioxide of manganese, containing about 70 per cent. of manganese and 7 per cent. of available oxygen.

*Rhodochrosite*.—Colour, usually rose red, with brown shades; streak, white. Hardness, 4; specific gravity, 3.5. Composition—carbonate of manganase, with about 45 per cent. of manganese. Contains no available oxygen.

*Franklinite*.—Colour, iron-black; streak, reddish-brown or black. Hardness, 6; specific gravity, 5. Composition—oxides of iron, zinc, and manganese, with about 10 per cent. of manganese.

*Rhodonite*.—Colour, pink tints usually, sometimes yellowish, greenish, and black. Hardness, 6; specific gravity, 3.5. Composition—silicate of manganese, with about 42 per cent. of manganese.

*Spessartite*.—Colour, dark red to brownish red, occasionally with a violet tinge. Hardness, 7; specific gravity, 4. Composition—silicate of manganese and alumina, with about 26 per cent. of manganese.

*Wolfram* and *Hübernite* are tungsten ores containing up to 15 per cent. of manganese.

*Other Manganese-bearing Minerals*.—See Dana's Mineralogy or Fermor's Manganese Ore Deposits of India\* for details, the latter containing full descriptions of new varieties and species of manganese-bearing minerals found in India.

Rhodochrosite occurs at Cloncurry, Warwick, Kilkivan, &c.; Rhodonite is found at Warwick, Degilbo, Kilkivan, and many other places. Many references to the occurrence of manganese ores will be found in the Queensland Mineral Index, which also gives particulars of localities and references to descriptions of deposits.

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\* See Bibliography, p. 285.

TABLE 72.—TYPICAL ANALYSES OF QUEENSLAND MANGANESE ORES.

Deposit.	Total Manganese.	Manganese Dioxide*	Iron.	Phosphorus.	Silica.	Comparative Quantities.
	%	%	%	%	%	
1. Amamoor Lode ..	52.7	69.3	1.9	0.11	9.4	Very large
2. Kandanga Lode ..	45.1	..	1.8	0.09	20.2	Large
3. Bollier Lode ..	49.1	..	1.6	0.09	12.4	Large
4. Mount Millar (A) ..	51.6	81.0	1.9	0.10	5.8	Small
5. Mount Millar (B) ..	49.2	77.6	2.0	0.10	6.2	Fair
6. Mount Millar (C) ..	45.4	71.8	3.1	0.07	8.6	Large
7. Mount Nansen ..	50.0	75.9	5.1	0.10	12.6	Fair
8. Mount Walli ..	50.3	48.1	3.9	0.07	9.4	Large
9. Omanama ..	53.1	67.8	3.0	0.07	9.6	Small
10. Nanango ..	49.1	74.0	2.2	0.08	2.1	Small
11. Mary Creek ..	44.1	66.1	2.7	..	8.6	Small
12. Pie Creek ..	56.6	89.0	2.7	..	0.7	Small
13. Devil's Mountain ..	47.5	66.0	1.4	..	12.5	Small
14. Yuraraba ..	53.3	67.4	3.0	0.05	5.0	Small
15. Elgalla ..	52.3	..	2.0	0.08	3.0	Small
16. Kilkivan ..	52.5	63.6	1.8	0.05	5.7	Small
17. Mount Kelly ..	52.4	61.3	..	..	..	Small

\* By available Oxygen.

## REFERENCE TO TABLE.

1. Lode 5 miles W.S.W. from Amamoor Railway Station to the S. of Gympie. (Bulk Sample.)
2. Lode is  $\frac{1}{2}$  mile N. of Imbil Station, near Selection 31v. (Bulk Sample.)
3. Lode is  $1\frac{1}{2}$  miles W. of Imbil Station near Selection 80v. (Bulk Sample.)
4. Near Gladstone. Typical composition of high grade ore.
5. Typical composition of second grade ore.
6. Typical composition of third grade ore.
7. Twelve miles S. of Gympie, on Eel Creek, branch of Mary Creek, Gympie.
8. Three miles S. of Kenilworth, 8 miles from Brooloo Station on Gympie-Mary Valley Line.
9. Near Omanama Railway Station, Gore District.
10. Three miles W. of Nanango Railway Station, Nancy Mine.
11. Cross's Selection 1336, 12 miles S.W. of Gympie.
12. W. of Selection 33, 9 miles W. of Gympie.
13. Near Woolooga Railway Station, Gympie District.
14. Railway Station, Gore District.
15. Close to Tungamull, Rockhampton District.
16. Five miles S. of Railway Station.
17. Twelve miles W. from Fa'ool, near Ulam Goldfield.

### Manganese Analyses and Percentages.

Table 72 is a selection of typical analyses, or partial analyses, made of a large number of samples recorded in the register of the Queensland Geological Survey, and may be considered representative of the qualities of the more important deposits examined up to the present time.

In the analyses of manganese ores required in making steel or manganiferous pig iron it is necessary to show the amount of metal present, not that of the oxides, and a variety of ores—not being silicates—can be utilised for this purpose so long as the percentages of impurities or non-essential ingredients are not too high. Before it is used in steel-making the ores are made into alloys in which only small quantities of iron is permissible, and therefore iron in manganese ores is penalised by the buyers if over a certain limit. Silica likewise is not required and is also penalised, although not so heavily as iron, while phosphorus is such an undesirable element that only mere traces will be allowed. References to ores containing over certain percentages of deleterious elements are given further on under the heading of “Quotations, &c.”

In other industries, more particularly those in which manganese is required for oxidizing purposes, such as in chemical and electrical work, it is very essential that the ore readily parts with some of its combined oxygen, and the only natural compound having this property is the dioxide. Only those minerals which contain a high percentage of this particular oxide are of any use, and, therefore, manganese ores for such purposes are tested for their “available oxygen.” Pyrolusite is found to give the best results in this respect, psilomelane, wad, braunite, and hausmanite also being useful in a subordinate degree. (*See under “Manganese-bearing Minerals” for the available oxygen of various natural compounds.*)

The Brazilian ores in the Lafayette (Quelvy) mines, near Minas Geraes, contain from 49 to 55 per cent. of metallic manganese, with from 1.5 to 7.0 per cent. of silica, 0.07 to 0.15 per cent. of phosphorus, and from 3 to 10 per cent. of moisture. The higher grades have the most moisture and are found in altered sedimentary rocks, the lower grades occurring in crystalline schists and gneisses. The Bahia mines produce psilomelane as lumps in clay deposits, the percentages of metallic manganese being 43 to 49, of silica from 3 to 4, phosphorus 0.01, and moisture from 2 to 3.

The Caucasian (Tchiatouri) ores average from 40 to 45 per cent. of metallic manganese, and are cleaned by washing to make an export product containing from 51 to 52 per cent., while special treatment by concentration yields from 80 to 90 per cent. of the dioxide, 8 per cent. of silica, and 0.16 per cent. of phosphorus. First grade standard is 50 per cent. metallic manganese, 8 per cent. silica, 0.16 per cent. phosphorus, and 10 per cent. moisture; second grade being 40 per cent. metallic manganese, 28 of silica, and 10 of moisture, with 20 per cent. of metallic manganese and 38 per cent. of silica in the tailings.

The Indian manganese deposits at Nagpur contain from 42 to 55 per cent. of metallic manganese, from 2 to 18 per cent. each of iron and silica, 0.04 to 0.65 per cent. of phosphorus, and about 1 per cent. of moisture. At Bálághát the ore contains about 50 per cent. of metallic manganese, about 7 per cent. of iron, between 1.6 and 6 per cent. of silica, 0.05 to 0.24 per cent. of phosphorus, and less than 1 per cent. of moisture. Bhándára percentages are 50–54 of metallic manganese, 4–10 of iron, 2–6.5 of silica, and 0.06–0.34 phosphorus. Chhindwára percentages are 49–55 manganese, 5–11.7 of iron, 5–10 of silica, and 0.06–0.28 of phosphorus.

Java produces manganese ore of very good quality, fairly high in manganese and low in impurities, and is evidently superior to much that is produced in Australia.

The principal Chilean deposits are at Carragal and Corral Quemada. The Carragal mines produce an ore having from 37 to 40 per cent. of metallic manganese, about 3 per cent. of iron, 5 to 12 per cent. of silica, 0.09 to 0.11 per cent. of phosphorus, and about 3.5 per cent. of combined moisture. At Corral Quemada the ore percentages are—manganese, 50; iron, less than 1; silica, 9.4 to 10; phosphorus, 0.01; and combined water, 1.

In the United States, the Arkansas mines are producing a high-grade ore containing from 45 to 52 per cent. of metallic manganese, 3 to 8 per cent. of iron, 2 to 8 per cent. of silica, and from 0.15 to 0.3 per cent. of phosphorus.

Percentages of Cuban ore, of which there is said to be a very large quantity available, vary from 44 to 56 of manganese, 0.3 to 2.4 of iron, 0.8 to 6.11 of silica, and 0.03 to 0.06 of phosphorus.

Japanese percentages are—metallic manganese, 48 to 51; silica, about 10; and phosphorus, 0.07. The ore in Spain is carbonate of manganese, and contains 28 per cent. of manganese when raw, about 49 when roasted, and up to 10 per cent. of

silica, with 0.1 per cent. of phosphorus. The percentages in the ore in Greece are—manganese, 17 (manganiferous iron ore) to 35 per cent., with silica up to 30, and iron up to 3.

The principal South Australian deposit at Pernatty Lagoon contains some very high grade ore, portions selected for chemical purposes showing on analysis 80.5 per cent. of dioxide, and 3.7 per cent. of ferric oxide. Another high grade ore contains 81.7 per cent. of dioxide and 5.6 per cent. of ferric oxide; while specially selected ore has a percentage of 89.2 per cent. of dioxide and 0.5 per cent. of ferric oxide. The average of a large number of samples taken by Mr. Winton\* was 50.57 per cent. of metallic manganese, 79.01 per cent. of dioxide, 4 per cent. of iron, 0.05 per cent. of phosphorus, and 2.6 per cent. of silica.

In Western Australia the Horseshoe Range deposits in the Geraldton District have been sampled in a number of places, and the results of the tests, without separating poor from rich portions, show an average of 41.66 per cent. of metallic manganese, 68.63 per cent. of dioxide, 15.32 per cent. of iron, and 1.04 per cent. of silica, but probably this percentage can be improved by dressing the ore.

In New South Wales the Grenfell mine, which is said to be the largest producing mine in Australia, yields manganese ore containing 50.5 per cent. of metallic manganese, 67.7 per cent. of manganese dioxide, 8.8 per cent. of silica, 2.1 per cent. of iron, 0.2 per cent. of phosphorus, 3.8 per cent. of baryta, and 2.7 per cent. of alumina (Hoskins).

The Queensland deposits are made up mostly of compact psilomelane. This class of ore at the Kandanga Lode, to the south of Gympie, contains about 45 per cent. of metallic manganese, of which about 30 per cent. is in the form of dioxide, with about 1.8 per cent. of iron, 20.2 per cent. of silica, and 0.09 per cent. of phosphorus. The Bollier Mine (near Kandanga) yields an ore containing 49 per cent. of metallic manganese, 1.6 per cent. of iron, 12.4 per cent. of silica, and 0.09 per cent. of phosphorus. In such grades there are large quantities of Kandanga and Bollier ore available. The Amamoor deposit, in the same district, contains 52 per cent. of metallic manganese, 69 per cent. of dioxide, 1.9 per cent. of iron, 9.4 per cent. of silica, and 0.10 per cent. of phosphorus, and of this grade enormous quantities are in sight.

The Mount Millar Mine near Gladstone contains three well-defined grades of ore, according to Mr. Ball.\* The first grade

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\* See Bibliography, p. 285.

ranges from 50 to 52 per cent. of manganese, and less than 80 per cent. of dioxide, of which there are limited quantities. The second grade ore ranges between 47 and 50 per cent. of manganese and a few thousand tons of this is available, while the third grade contains from 40 to 47 per cent. of manganese of which many thousand tons are in sight. Mount Millar ore generally contains a high proportion of silica, having a variation between 5 and 15 per cent., but when selected makes a very good ore for steel-making, although somewhat inferior for chemical and electrical uses.

Some of the other Queensland deposits, particularly about Eel and Pie Creeks near Gympie, show good results when samples of the ore are tested, and no doubt several of them will be worked either for their metallic contents or for dioxide, although from such information as is available their extent does not appear to be large.

The percentage of recovery in mining the ore and putting it into a marketable condition varies, of course, with the local conditions, but the Russian practice shows that the easily-broken ore of the Caucasus is worked with an initial mining loss of 25 per cent., with 37 taken out as lump ore, 25 per cent. recovered as friable ore, and 13 per cent. lost in washing the friable ore, the total recovery being 62 per cent., the total loss 38 per cent. In Queensland the ores are almost always very hard, and therefore very suitable for smelting, so that such a large percentage of loss in working the deposits would not take place.

### Metallurgical and Chemical Notes.

Metallic manganese has a slightly reddish lustre, but otherwise has somewhat the appearance of cast iron. It is hard and brittle, has a specific gravity of 7 to 8, and melts at  $3,452^{\circ}$  F. Its composition is 99.9 per cent. of manganese, with traces of iron, silicon, and carbon.

The metal is variously used in the preparation of a number of alloys principally made up of manganese and iron, with very small quantities of carbon, silicon, nickel, chromium, tungsten, copper, phosphorus, &c., &c.

The two principal manganese alloys are ferro-manganese and spiegeleisen, others of lesser importance being silico-manganese, silico-spiegel, phospho-manganese, and cupro-manganese, any two of which may be combined to form other more complicated alloys, all being used in small or large quantities in the manufacture of steel and other industrial metals.

Ferro-manganese and spiegeleisen are identical alloys so far as their constituents are concerned, but the proportion of the elements in each are different, and large quantities of the spiegeleisen would be required to produce the same effect in a steel as small quantities of the ferro-manganese. Sometimes the use of spiegeleisen is objectionable in containing a high percentage of carbon, which increases instead of reduces the carbon contents of the steel. Often the ferro-manganese is put into the steel to destroy the effects of any excess of carbon and not for the purpose of introducing the manganese.

The manganese ores used in making ferro-manganese alloys should contain at least 40 per cent. of manganese, and not more than 0.2 per cent. of phosphorus. The latter is not altogether eliminated in the furnace fusions and so contaminates the metal, while silica and alumina in the ore combine with the fluxes and readily form slag. Iron in the manganese ore is not detrimental in very small amounts, but copper is a deleterious substance. Zinc is not a serious impurity because it is volatile on heating, and can be easily removed by a preliminary roasting of the ore with coke or anthracite.

The physical conditions of the ore is also an important factor, as soft ores will not withstand the crushing strain of the large quantities of material charged into a shaft furnace and thus smothers the draft.

Manganiferous iron ores containing from 10 to 20 per cent. of manganese are useless for making ferro-manganese or spiegeleisen, but are utilised in making manganiferous pig, and cast iron made from this is less corrosive than ordinary kinds. The demand for manganese in the making of spiegeleisen is on the decrease, while for making ferro-manganese the demand is becoming greater.

*Ferro-manganese* is a white or grey alloy with a bright lustre and a granular texture. It requires a much greater heat for its manufacture than spiegeleisen, 1,350° to 1,550° F. being required, and is usually a blast-furnace product, although also made in the electric furnace. In the former case the type used is the usual pig-iron furnace, and in the latter the form is usually rectangular with carbon or magnesite linings, but sometimes with water-jacketed firebrick. The fuel in the blast furnace is mostly coke, but anthracite and charcoal, or mixtures of two, are used, while in the electric smelter the heat is supplied from a 55 volt to 85 volt current. The composition of ferro-manganese varies between 40 and 80 per cent. of manganese, 10 to 40 per cent. of iron, 1.5 to 0.5 per cent. of silicon, 4 to 7 per cent. of

carbon, and 0.1 to 0.2 per cent. of phosphorus. The Hoskins Steel Works, at Lithgow, produces a ferro-manganese containing the following percentages:—Manganese 80, iron 11, carbon 7, silicon 2, phosphorus 0.4, and trace of sulphur (Hoskins). The ferro-manganese produced by the Broken Hill Proprietary at Newcastle contains about 70 per cent. of manganese.

In furnace work the loss of manganese becomes excessive if too much slag is made, therefore the quantity of flux is reduced to the lowest possible minimum; the slag, however, must be basic, and therefore requires a greater heat to keep it molten than in smelting iron ores, and to produce this greater heat a blast is used having a high temperature.

A ferro-manganese—or metallic manganese to be more correct—is now made which has the following constituents:—

	Per cent.		Per cent.
Manganese ..	96.80	Silicon ..	1.40
Iron ..	1.40	Carbon, &c. ..	0.40

This metal should be very valuable in enabling a better control being kept of the carbon contents of the steel, and its manufacture brings the metallurgical production of ferro-manganese to perfection.

In 1918 the ferro-manganese standard in America was 70 per cent. manganese as a result of the stringency caused by war conditions. This was followed by a lowering of the grade of manganese ores to a standard of 35 per cent., but post-war conditions may necessitate the standard being raised to the pre-war level.

As a substitute or partial substitute for ferro-manganese an alloy is being used to a limited extent which contains titanium, but little is known about its action.

The uses of ferro-manganese are numerous. It will act as a cleanser of any iron which might have been oxidised by the air blast in the converter, the manganese in the alloy becoming oxidised in the charge and then combining with the slag to form a silicate, and as such is easily removed. It will serve as a means of introducing small quantities of carbon into a steel, without which the product might only be wrought iron, and introduced in this way the carbon will not separate out as graphite but will take the form of iron carbide, a feature specially useful in the manufacture of certain kinds of manganese steel by both Bessemer and open hearth processes.

*Spiegeleisen* is a white or grey alloy of bright metallic lustre and with a coarsely crystalline flaky structure. It is ordinarily a product of the blast furnace treating manganimiferous iron ores,

in the same way that ferro-manganese is made from manganese ores, and contains between 10 and 30 per cent. of manganese, 20 per cent. being considered the standard of quality. It also contains from 60 to 85 per cent. of iron, about 4 per cent. of carbon, about 1 per cent. of silicon, and about 0.1 per cent. of phosphorus. The Hoskins Steel Works, at Lithgow, produce a spiegeleisen having the following composition:—Manganese 20 per cent., iron 72.5 per cent., carbon 5 per cent., silicon 2 per cent., phosphorus 0.2 per cent., and trace of sulphur. (Hoskins.)

The alloy is used in much the same way as ferro-manganese although useless in the more delicate refinements of steel manufacture. A further use for both ferro-manganese and spiegeleisen in ordinary steels is in neutralising the bad effects of sulphur and phosphorus, which are converted into manganese sulphide and phosphide respectively, and which then do no harm to steels.

*Silico-spiegel* has the same constituents as spiegeleisen but the silica percentage is much greater, usually being from 6 to 16 per cent., with from 20 to 40 per cent. of manganese. The carbon contents are very low when compared to other iron-manganese alloys and vary from about 3 per cent. to less than 1 per cent., the proportion of this element as a rule being small in the alloy when the silicon is high. The alloy produces great tenacity in a steel which does not contain more than 1 per cent. of both manganese and silicon and which requires to be quenched. *Silico-manganese* is somewhat similar to silico-spiegel although both the silica and manganese percentages are higher, the iron correspondingly low, the approximate figures being, respectively, 60-70, 25, and 4-15. Both silico-spiegel and silico-manganese can be made in the blast furnace, but preferably in the electric furnace.

*Cupro-manganese* is a crucible or reverberatory furnace product variably containing from 4 to 30 per cent. of manganese, and made by highly heating manganese dioxide or carbonate with metallic copper and a fluxing ingredient. It is used in small quantities to give copper greater strength and tenacity, the action being to reduce any oxide of copper which might have been formed undesirably and which requires to be eliminated. In larger quantities the alloy introduced into molten copper will produce hardness, a quality which makes it very useful. It is added to copper to form *manganese bronze*, and to copper and zinc to form *manganese brass*, while added to ferro-manganese, copper, and zinc it forms manganese german silver or *silver*

*bronze.* When introduced into copper to form manganese bronze the object is to make the cupro-manganese a carrier for a small quantity of iron, the metal which hardens the copper, but ferro-manganese is used for this purpose as well. Manganese bronze, without aluminium, is used for rolling and wire drawing, but this metal is necessary when the bronze has to be cast in sand.

*Manganese Steel.*—Ferro-manganese and spiegeleisen were first used as a means of introducing small quantities of manganese into steel with the object of giving to this metal greater strength and durability, but it was found that when the percentage of manganese reached over  $1\frac{1}{2}$  or 2 per cent. the steel became very brittle and unworkable. Subsequently it was discovered that with about 7 per cent. of manganese present the steel lost its brittleness, and with about 14 per cent. it became very hard and tough, while with over 20 per cent. all its bad brittle qualities reappeared.

The deterioration experienced with the high amount of manganese was considered to be partly due to the effect of the carbon, and it is considered that one of the uses of carbon-free ferro-manganese in the future will be to make steel very high in manganese and very low in carbon.

Manganese steel is usually a hard ductile metal when rapidly cooled and a brittle one when slowly cooled. The metal is generally cast into the shapes in which it is to be used, such as shoes, dies and plates for stamper batteries, linings for roller or ball mills, jaws for rock breakers, and truck and car wheels. It is also used for rail curves and junctions, couplings, cog-wheels, and other parts of machinery where the friction is very great and where great tensile strength and hardness are requisite qualities. Until recently it could not be worked with machine tools and all the finishing had to be done with emery or carborundum wheels, but an exceedingly hard alloy called stellite, made of chromium, cobalt and tungsten is now used with good results in the tools required for working such hard steels.

The toughness of manganese steel and its resistance to fracture is increased by heating the metal to certain temperatures and quenching in water, an effect quite contrary to that produced in carbon steels when similarly treated. It is also less liable to deterioration from over heating, so that much freedom is permitted in raising the temperature to produce other beneficial effects in the course of manufacture.

One important application for manganese steel is based on

the property it possesses of being non-magnetic, and in large engineering works and foundries the covers for the electro-magnetic clutches used in lifting iron are made of it.

Complex manganese steels are produced by combining ordinary manganese steel with alloys such as nickel-manganese, manganese-chromium, or manganese-silicon, the effects being somewhat similar to that produced by manganese alone, the advantages gained being in the costs of production.

*Other Manganese Alloys.*—Heussler's magnetic alloys are made up of copper, manganese and aluminium, and are magnetic when gradually cooled but non-magnetic if quenched when heated to a high temperature. Alloys of manganese with various other metals are also magnetic but very little is known about their properties.

Electric resistance alloys are also made up of manganese with copper and nickel, and the most resistant of alloys is a nickel-manganese steel. (See Tables 55 and 56, pp. 199-200.)

Manganese will also harden various other metals, and one of its most useful applications is in hardening aluminium.

*Manganese Flux.*—Manganese oxides used as fluxes in smelting copper, silver, and other ores are distinctly advantageous when mixed with iron oxides and limestone, the slags becoming more fluid with the formation of complex silicates of manganese, iron, and lime, and consequently much cleaner from reduced metal.

*Ferro-manganese Slags.*—Large quantities of manganese are taken up by the slags in the manufacture of ferro-manganese and ferro-phosphorus and the utilisation of this furnace refuse for the recovery of manganese has been a problem for solution. With an 80 per cent. ferro-manganese product the resulting slag usually contains about 10 per cent. of manganese, but as much as 14 per cent. of the metal is sometimes present, while with a lower grade product the proportion of manganese wasted is somewhat greater. The manganese requirements of Germany during the war were said to be reduced as a result of new discoveries in steel making, but the opinion has been expressed that the discovery is really a method of recovering the enormous quantities of manganese which are locked up in the old slags from the ferro-manganese furnaces.

*Leaching Manganese from Ores.*—An interesting series of experiments were tried in America during the war to determine whether manganese can be leached out of low-grade ore by

means of the sulphur dioxide fumes obtained from roasting furnaces. The trials showed that manganese sulphate can be manufactured in this way, but that the cost of production was high when compared to cost when using oversea supplies of high-grade manganese ores for the same purpose.\*

### Manganese Compounds and Their Uses.

The dioxide is practically the only form of manganese which can be utilised in chemical operations, pyrolusite and psilomelane being its principal source. Manganite and braunite are not used for chemical purposes, but with other manganese-bearing minerals containing a high percentage of the metal, they can be applied to the manufacture of ferro-manganese. The two former minerals easily part with portion of their oxygen in treatment, and this factor alone makes them suitable for the manufacture of chemical compounds.

*Chlorine Manufacture.*—Manganese dioxide was once used on a large scale in the production of chlorine, the operation consisting in dissolving the oxide in hydrochloric acid and thereby liberating the chlorine contained in the latter. The same effect is produced by the action of sulphuric acid on a mixture of the dioxide and sodium chloride, although the reactions are different. More recent processes are now in operation for making chlorine by electrolysis or by a fusion process, and so successfully that its manufacture with the use of manganese dioxide as a reagent may now be considered to be obsolete.

*Generating Oxygen.*—The manganese dioxide can be utilised direct for the manufacture of oxygen simply by highly heating it in a retort, but when mixed with chlorate of potash, and without any apparent change in itself, will cause this salt to part with some of its oxygen at a low temperature. Oxygen is driven off while the dioxide changes to a tetroxide, the decomposition being complete when the charge is kept at a white heat for a day or more, the residual oxide being of a red colour.

Another method of producing oxygen consists in heating manganese dioxide or permanganate of potash with sulphuric acid, but processes are also used for the manufacture of oxygen in which manganese dioxide is not required, such as in the fractional distillation of liquid air and the electrolysis of water, and no doubt the use of manganese for this purpose, as with chlorine, will be a thing of the past when operations are conducted on a commercial scale.

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\* Manganese U. S. Bull. 173. See Bibliography, p. 286.

*Disinfectants.*—Manganese is applied largely in the making of permanganate of potash and soda, both of which, like chlorine, are powerful disinfectants. These compounds are somewhat unstable and readily part with a portion of their oxygen in coming in contact with various organic compounds, which they oxidise and render harmless and odourless. Condy's Fluid is a solution of permanganate of soda, and is commonly used as a domestic disinfectant and for other purposes.

*Medicinal Uses.*—Permanganate of potash is one of the remedies for snake bite, the flesh first being scarified with a knife and some of the crystals of the salt then inserted in the wound. The available oxygen in the permanganate mixes with the poison, which becomes oxidised and thereby loses its virulence. The salt in solution is commonly used as a wash for wounds and sores to prevent blood poisoning and has healing qualities.

*Chemical Uses.*—Permanganate of potash is a reagent in volumetric analysis for the estimation of manganese, iron, lead, and lime, the action involved in the operations being the furnishing of oxygen by the permanganate in solution to another substance in solution, the unknown quantity of the latter being determined by the known amount of the reagent required to produce discolouration in the permanganate solution. There are other chemical uses for manganese compounds but they are of minor importance.

*Varnish and Paint Dryers.*—Manganese dioxide possesses the property of oxidising certain oils used in the manufacture of paints and varnishes, and gives to them the quality of quickly drying. The simple boiling of some oils is sufficient to produce this effect, but the introduction of manganese dioxide or some other oxidising reagent is necessary with others. Manganese oxide or borate is usually the form in which the manganese is applied to the manufacture of dryers, but the sulphate, acetate, oxalate, oleate and linoleate are frequently used. The oxide, however, makes the oils dark, and if oils are required to be of a light colour manganese sulphate is preferred.

The borate of manganese, which is commonly used as a dryer, is made by adding a hot solution of borax to a solution of the sulphate, the precipitate formed being the borate required. The linoleate, which produces a good drying oil, is made by first mixing a soap solution (made with linseed oil and soda) with a solution of the sulphate. The semi-solid mass formed is mixed with 5 times its weight (in lbs.) of linseed oil, and this is poured into a further 10 gallons of the same oil at a temperature of 250 degrees F. The resinates, oxalates, and acetates, which

are not so commonly used, are somewhat more complicated in their method of manufacture.

In the application of manganese compounds for this purpose it is its oxidising capacity which makes it effective, and some doubt has been expressed as to whether its action is a chemical one or simply catalytic, whether its production of chemical changes in other substances is produced without being itself changed. It is found that this oxide can be used repeatedly for oxidising oils, and only requires to be dried and exposed to the atmosphere to again become effective.

Oxides of lead, copper, zinc, and other metals with and without manganese compounds are also dryers of oil but the manganese dioxide is much more effective.

*Pigment Making.*—Manganese wad is used in the preparation of the brown pigments known as umber and cappagh brown, and the most suitable variety for the purpose is that containing between 20 and 40 per cent. of both ferric oxide and manganese dioxide. Other mixed oxides of manganese and iron are used in making velvet brown and chestnut brown, and these when roasted produce burnt umber whose shades depend partly on composition, partly on the time taken in the roasting, and partly on the temperature at which the roasting is done.

Cassel green is produced by heating manganese nitrate or oxide with barium nitrate, the process being complicated. Manganese sulphide forms another green pigment, and manganous oxide a similar one if precipitated from the sulphate solution with soda. Green manganese pigments are not much in demand but manganese umbers are commonly used.

*Bromine Manufacture.*—In the manufacture of common salt from sea water the bittern remaining after the precipitation of the salt and other chlorides and sulphates contains, amongst other substances, a number of bromide compounds. Manganese dioxide, sulphuric acid, and bittern are mixed together, which causes chlorine to be evolved, this gas then acting on the bromide compounds to form chlorides and free bromine, the latter then being collected as a liquid in a condenser.

*Dye Substance.*—Cotton fabrics are dipped in a solution of manganous chloride and then in another solution of caustic soda, a brown colour being produced which consists of a hydrate of manganese. This manganese brown is also used as a colour base on which to dye aniline black, the process being considered an effective one because the hydrate assists the aniline by parting with some of its available oxygen.

Permanganate of potash with other substances is also used to produce a brown colour in calico. It acts as a mordant for other dyes.

The permanganate is very effective as a stain for wood, the colour being brown in imitation of walnut.

*Glass-making and Porcelain Glazing.*—The dioxide is used extensively in destroying the greenish colour produced by the ferric oxide usually present in the ingredients required in the manufacture of flint glass. It is the oxygen which produces the change not the manganese.

Colourless glass on long exposure to sunlight becomes pink or purplish, a result of the oxidation of the manganese, this colour also being produced in the glass if more than the right proportion of manganese is used to neutralise the iron discolouration. Used in excess manganese will make glass quite black.

Glazed bricks and pottery are also coloured by manganese dioxide, the black, chocolate, brick red, grey and buff colours being produced by arranging the kiln temperatures and air supply, and by mixing the dioxide with other ingredients. The quality of the ore required for this purpose is not high, and the presence of silica is not detrimental. Black tiles can be made by mixing manganese ore in the body clay, and black pottery can be produced in the same way.

*Electric Batteries.*—Manganese dioxide is one of the solid constituents of the Lechanché cell, its function being to allow more freedom of action between the zinc and carbon poles. In the chemical changes which take place between the solution of ammonium chloride and the zinc carbon there is a resulting accumulation of hydrogen bubbles around the carbon which retards chemical action, and therefore electrical action, and if manganese dioxide is mixed with the carbon pole or painted on to it the gas accumulation is prevented and the chemical action not interfered with.

In dry cells manganese dioxide is also employed and the same oxidising action goes on. In one form of cell thin paper is tinned on one side and coated with the dioxide on the other, and an accumulation of discs made of this combination and packed into tubes with the necessary connections constitute the cells used in some electric hand lamps. Other cells are made of a carbon core with graphite, manganese dioxide, and ammonium chloride surrounding it. This is contained in a zinc case with a gelatinous substance between.

The most effective dry cell is one in which the negative pole is pure sheet zinc made into the form of a case, with a lining of blotting or other very porous paper to act as a diaphragm and as an absorbent for the electrolyte, the positive pole being made up of a coke carbon electrode surrounded with a mixture of manganese dioxide and graphite, with an electrolyte made up of a solution of zinc and ammonium chlorides. The manganese dioxide must be rich in available oxygen and the graphite pure enough to be a good conductor, both minerals to be uniform in grain and sufficiently porous when mixed to allow free percolation of the electrolyte, while the coke carbon has to be highly heated to make it a good conductor.

The first action appears to be between the metallic zinc and the ammonium chloride which forms zinc chloride and generates ammonia and hydrogen, this action producing the polarization desired. The next action apparently is when the cell is not discharging, the manganese dioxide and zinc chloride reacting on the other constituents to produce regeneration and depolarization. It is the power of recovery that makes the dry cell so useful, and the desideratum is to obtain a combination of ingredients which will have a regenerative action equal, or nearly equal, to the polarizing action, and therefore give a long life to the cell.

For electrical purposes generally the ore must be of the highest quality, that is, containing about 85 per cent. of dioxide, and when made of this grade the cells last a long time, but made of low grade material soon lose their power. Iron oxide is also injurious, and should not be present to the extent of more than 1 per cent., while silica in being inert is not detrimental.

*Ornamental Stone.*—Rhodonite, the natural silicate of manganese, is variously tinted pink and black, and being a pretty stone and nearly as hard as quartz is suitable for inlaid work. The Rhodonite from The Glen near Warwick is very attractive when made into brooch stones, sleeve links, pendants and other articles of jewellery.

#### **Production, Values, &c.**

The Bessemer and open-hearth processes of manufacturing steel are to be credited with the utilisation of 90 per cent. of the manganese ore production of the world, and many of the countries which were producing the ore in only small quantities before these processes were discovered are now yielding it in thousands of tons annually.

Of all countries Russia is the most productive in manganese ore, her total yield up to the present being about one-third that of the whole world. India has produced one-quarter of the world's output, Brazil has one-tenth to her credit, and Germany one-sixteenth.

The Commonwealth production is a small one, being 46,585 tons up to the end of 1918, although its resources are not yet known. Queensland has produced a little less than one-half the total yield, the rest principally coming from South Australia and New South Wales.

Table 73 gives the total production of manganese ore by countries up to the end of 1918 (with the exception of a few countries of which statistics are not available) together with the values of the production, and the average value per ton. Hungary, Belgium, and Russia produce the ores of lowest value, while Canada and South Australia produce those of highest value. There is very little difference between the total value of Russian and the Brazilian production, but that of India is far in excess of either.

Table 74 contains the annual production of the principal countries during the six-year period ending 1918, the statistics showing quantities, total values, and average values per ton. The Russian production has been a negligible quantity for a few years, that of India having a normal variation, while the Brazilian output increased considerably as a result of the war. Values increased all round with these abnormal conditions, but Brazilian ores obtained the highest prices. The United States values per ton were £6 12s. 4d. in 1917, and the small production of South Australia was valued at £16 11s. 9d. per ton. Germany must be producing large quantities of ore at the present time, although no figures are made available.

In Table 75 the yields of ferro-manganese and spiegeleisen are given for a number of years. A very large annual increase is shown in the production of both alloys during the 1914-1918 period, although the proportional increase in ferro-manganese far exceeds that of spiegeleisen both in total quantity and total value. The value per ton for the United States shows an extraordinary increase, the ferro-manganese in 1918 being over five times that of 1914, and spiegeleisen over three times. The United Kingdom figures available are too fragmentary to institute a comparison.

The imports of manganese ores by countries are shown in Table 78. The information available is very complete so far as the United States is concerned, but very meagre otherwise. The

TABLE 73.—Total PRODUCTION OF MANGANESE ORE BY COUNTRIES,  
1860-1918.*(Compiled from various sources.)*

Country.	Years.	Production.	Values. (Approximate.)	Value per Ton (Approx.)
		Tons.	£	£ s. d.
Russia .. ..	1881-1916	13,762,516	9,410,669	0 13 8
India .. ..	1893-1918	9,827,745	14,470,562	1 9 5
Brazil† .. ..	1894-1918	4,430,680	8,937,473	2 0 4
Germany .. ..	1852-1913	2,186,777	2,092,860	0 19 2
Spain .. ..	1860-1917	1,369,787	*1,183,602	0 17 3
United States ..	1835-1915	901,095	3,503,254	3 17 9
France .. ..	1873-1913	590,687	*733,709	1 4 10
Chili § .. ..	1884-1906	556,938	717,061	1 5 9
Turkey † .. ..	1888-1910	518,622	*2,077,896	4 0 0
Austria-Hungary ..	1856-1917	668,857	*424,896	0 12 8
Japan .. ..	1881-1918	384,227	*462,954	1 4 4
Cuba ‡ .. ..	1888-1918	442,536	*1,171,657	2 12 1
Belgium .. ..	1880-1909	307,722	155,846	0 10 1
Greece .. ..	1887-1916	264,547	*272,038	1 0 7
United Kingdom ..	1860-1917	259,003	*411,858	1 11 8
Sweden .. ..	1863-1917	199,000	*255,247	1 5 8
Italy .. ..	1860-1916	194,814	*294,824	1 10 3
Bosnia and Herze- govina .. ..	1882-1914	169,583	*208,550	1 4 7
Portugal .. ..	1881-1912	85,840	*164,325	1 18 3
Canada .. ..	1886-1918	11,581	85,974	7 8 7
New Zealand .. ..	1878-1911	19,364	61,905	3 3 11
South Australia ..	1882-1918	14,405	69,468	4 16 5
New South Wales ..	1890-1918	12,733	12,124	0 19 0
Victoria .. ..	To end of 1916	247	919	3 14 5
Queensland .. ..	1894-1918	19,200	72,648	3 15 8
Totals .. ..	..	37,198,516	47,252,319	

\* Estimated in part.

† Export figures.

‡ The figures for 1914, 1915, and 1916 are export quantities and values.

§ Principally export figures.

TABLE 74.—ANNUAL PRODUCTION OF MANGANESE ORE BY PRINCIPAL COUNTRIES, 1913-1918.

(Compiled from various sources.)

Country.	YEARS.					
	1913.	1914.	1915.	1916.	1917.	1918.
<i>Russia</i> .. Tons	†1,152,500	†725,355	†49,210	†147,630	..	..
Value £	*1,234,000	*777,000	*53,000	*200,000	..	..
Value per Ton £	1 1 5	1 1 5	1 1 5	1 2 8	..	..
<i>India</i> .. Tons	815,047	682,898	450,416	645,204	590,813	517,953
Value £	1,211,034	877,264	929,546	1,487,026	1,501,080	1,481,735
Value per Ton £	1 9 8	1 5 8	2 1 3	2 6 1	2 10 10	2 17 2
<i>Brazil</i> .. Tons	†120,367	†180,728	†284,109	†495,180	†524,035	†387,172
Value £	*170,500	287,894	548,422	1,475,199	*1,573,000	*1,161,000
Value per Ton £	1 8 4	1 10 8	1 18 7	2 19 7	3 0 0	3 0 0
<i>Japan</i> .. Tons	17,947	16,806	25,461	7,738	..	56,109
Value £	18,744	*17,000	*34,000	*10,000	..	*203,000
Value per Ton £	1 0 11	1 0 10	1 6 8	1 5 8	..	3 12 3
<i>Spain</i> .. Tons	21,333	11,936	14,328	13,947	56,565	..
Value £	*13,000	*7,100	*8,900	*8,688	83,965	..
Value per Ton £	0 12 2	0 12 5	0 12 5	0 12 6	1 9 8	..
<i>United Kingdom</i> Tons	5,393	3,437	4,651	5,139	9,941	..
Value £	4,072	2,931	*3,800	*4,300	*8,300	..
Value per Ton £	0 15 1	0 17 0	0 16 7	0 16 9	0 16 8	..
<i>United States</i> Tons	4,048	2,635	9,700	31,474	129,405	305,869
Value £	8,434	5,704	23,606	136,725	856,192	1,717,747
Value per Ton £	2 1 10	2 3 3	2 8 8	4 6 10	6 12 4	5 12 4
<i>Sweden</i> .. Tons	3,938	3,585	7,487	8,753	19,559	..
Value £	*8,000	*7,300	*15,000	*17,000	*38,000	..
Value per Ton £	2 0 7	2 0 8	2 0 0	1 18 10	1 18 10	..
<i>Italy</i> .. Tons	1,596	1,623	12,378	17,860	..	..
Value £	*2,200	*2,200	*16,900	*24,000	..	..
Value per Ton £	1 7 6	1 7 1	1 7 3	1 6 11	..	..
<i>Cuba</i> .. Tons	..	†1,300	†5,141	†30,563	†44,512	†82,974
Value £	..	*3,600	14,469	107,122	127,586	573,165
Value per Ton £	..	2 16 3	2 16 3	3 10 1	2 17 4	6 18 2
<i>Queensland</i> .. Tons	27	6	200	643	21	†1,299
Value £	163	27	820	2,793	105	4,151
Value per Ton £	6 0 9	4 10 0	4 2 0	4 6 10	5 0 0	3 3 11
<i>New South Wales</i> Tons	..	..	713	1,924	3,721	†6,512
Value £	..	..	535	1,443	2,791	6,228
Value per Ton £	..	..	0 15 0	0 15 0	0 15 0	0 19 1
<i>South Australia</i> Tons	..	..	250	544	264	1,080
Value £	..	..	563	2,700	1,597	†17,876
Value per Ton £	..	..	2 5 0	4 19 3	6 1 0	16 11 9
<i>Austria-Hungary</i> Tons	40,246	29,341	22,131	22,674	48,851	..
Value £	*20,000	*15,000	*11,000	*11,000	*24,000	..
Value per ton £ about	0 10 0	0 10 0	0 10 0	0 10 0	0 10 0	..

\* Estimated.

† The figures for 1919 are—Queensland, 20 tons, value £103; New South Wales, 4,651 tons, value £13,953; South Australia, 298 tons, value £1,490.

‡ Export figures.

United Kingdom has only published summarised statistics, while other countries, including the Commonwealth, have none at all although we know that for steel-making large imports into the Commonwealth have been made. The United States imported large quantities of ore from Cuba during the years of the war;

in fact, the war almost created the trade with that country, while Costa Rica, Panama, and Mexico also furnished ore exclusively to the United States during and subsequent to the war. The imports into the United Kingdom were from the old established fields of India and Brazil.

Table 79 shows the imports of manganese ore by the Commonwealth, the whole of which has gone to New South Wales. During the year 1918-1919 the values of these exports were about £4 19s. 2d. per ton against 19s. per ton for the local production. New South Wales has also been importing ore from Queensland, but as the two States are within the Commonwealth the information as to quantities and values is not published.

Table 76 showing exports of manganese ore by principal countries indicate the trade done by the three principal countries—India, Russia, and Brazil—but, with the exception of Spain, very little data are available from other countries.

In Table 77 are given the exports of manganese ore from Australia, from which it is evident that the trade is merely nominal, the only recent exports being those of South Australia and Victoria. Probably the Victorian exports are those of ore received from South Australia as the ore has not been produced in the former State, according to official returns.

Ferro-manganese and spiegeleisen production statistics are given in Table 75. The only country furnishing complete returns is the United States, those from the United Kingdom being for two years only. Ferro-manganese is being manufactured in New South Wales by the Hoskins Works at Lithgow, and although no returns are published, many thousands of tons have been manufactured.

This company started manufacturing in 1915, and since then their blast furnace on several occasions has been producing either ferro-manganese or spiegeleisen, most of which have been used in their own works, although a large quantity has been furnished to the Broken Hill Proprietary for their steel works at Newcastle, while other supplies have been forwarded to other Australian and Japanese users.

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TABLE 75.—PRODUCTION OF FERRO-MANGANESE AND SPIEGELEISEN BY COUNTRIES, 1914-1918.

*Ferro-Manganese.*

Country Producing.	YEARS.				
	1914.	1915.	1916.	1917.	1918.
United States .. .. Tons	100,731	144,260	224,103	260,225	306,076
Value £	925,053	1,927,800	6,275,718	11,235,577	14,384,516
Value per Ton £	9 3 8	13 7 3	28 0 0	43 3 6	47 0 0
United Kingdom .. .. Tons	336,354	255,464	..	..	..
Value £	*4,709,000	*5,109,000	..	..	..
Value per Ton £	14 0 0	20 0 0	..	..	..

\* Estimated.

*Spiegeleisen.*

Country Producing.	YEARS.				
	1914.	1915.	1916.	1917.	1918.
United States .. .. Tons	76,625	114,556	182,837	189,241	263,861
Value £	330,445	500,531	1,282,958	2,032,549	3,599,269
Value per Ton £	4 6 3	4 7 4	7 0 4	10 14 10	13 12 10
United Kingdom .. ..	Included	with Ferro-	Manganese.		

**Quotations, Markets, &c.**

Before the war the prices of manganese ore in London varied but little from year to year, but with the altered conditions prices fluctuated considerably with a strong upward tendency, rising finally to 3s. 6½d. per unit for Indian ore in the latter part of 1918. During this year in New York prices also became inflated, and went as high as 5s. 7½d. per unit. The year 1919 saw a reduction in values to about an average of 2s. 3d. in New York and 2s. 4d. in London, although prices have not been reduced to those prevailing before the war. In both London and New York, in 1920, prices became somewhat uniform, the averages being 3s. 9d. and 3s. 3d. respectively.

Indian and Brazilian ore under normal conditions is invariably higher in price per unit than Russian ore, and in Table 80 is shown this variation in the years 1912 to 1914. In this table the maximum percentage is quoted at 50 but under war conditions the standard was raised to 60 per cent.

TABLE 76.—EXPORTS OF MANGANESE ORE BY PRINCIPAL COUNTRIES, 1913-1918.†

Country Exporting.	YEARS.						Country Importing.
	1913.	1914.	1915.	1916.	1917.	1918.	
India .. Tons	708,031	718,049	418,733	580,328	481,623	350,950	United Kingdom, United States, France, &c.
Value £	*1,052,000	*922,000	488,077	766,717	603,367	481,338	
Value per ton £	1 9 9	1 5 8	1 2 10	1 6 5	1 5 1	1 7 5	
Russia .. Tons	1,152,500	725,650	49,210	147,630	..	..	United Kingdom, Germany, Bel- gium, United States, &c.
Value £	*1,234,000	*777,000	*53,000	*200,000	..	..	
Value per ton £	1 1 5	1 1 5	1 1 5	1 2 8	..	..	
Brazil .. Tons	120,367	180,728	284,109	495,180	524,435	387,172	United States, United King- dom, &c.
Value £	170,500	287,894	548,422	1,475,199	*1,573,000	*1,161,000	
Value per ton £	1 8 4	1 10 8	1 18 7	2 19 7	3 0 0	3 0 0	
Spain .. Tons	27,353	8,843	8,992	6,707	..	..	United Kingdom
Value £	*27,353	*8,843	*8,992	*6,707	..	..	
Value per ton £	1 0 0	1 0 0	1 0 0	1 0 0	..	..	
Cuba .. Tons	..	1,300	5,141	30,563	44,512	82,974	United States
Value £	..	3,600	14,469	107,122	127,586	573,165	
Value per ton £	..	2 16 3	2 16 3	3 10 1	2 17 4	6 18 2	

\* Estimated.

† Compiled from Min. Ind., Min. Resources, U.S., Eng. and Min. Jour. and Records, Geol. Surv., India.

TABLE 77.—EXPORTS OF MANGANESE ORE BY THE COMMONWEALTH, 1915-1919.\*

Country Exporting.	Year.	Quantity.	Value.	Country Importing.	Quantity.
		Tons.	£		Tons.
New South Wales	1915-1916	491	5,414	{ United Kingdom	105
Victoria ..	1915-1916	30	270	{ United States ..	416
New South Wales	1916-1917	69	638	{ United Kingdom	155
South Australia	1916-1917	155	1,588	{ United States ..	69
New South Wales	1917-1918	96	873	{ United Kingdom	137
South Australia	1917-1918	164	3,698	{ United States ..	96
				{ Japan .. ..	27
Victoria ..	1918-1919	362	7,000	{ United Kingdom	396
South Australia	1918-1919	343	7,290	{ United States ..	209

\* Official Statistics, Commonwealth of Australia.

TABLE 78.—IMPORTS OF MANGANESE ORE BY UNITED STATES AND UNITED KINGDOM, 1913-1918.\*

Country Importing.	YEARS.						Country Exporting.
	1913.	1914.	1915.	1916.	1917.	1918.	
<i>United States</i> Tons	70,200	113,924	275,579	471,837	512,517	345,877	Brazil
Value £	92,725	153,494	466,841	1,487,463	1,787,145	2,119,612	
Value per ton £	1 6 5	1 6 11	1 13 10	3 3 6	3 9 9	6 2 6	
Tons	141,587	103,583	36,450	51,960	48,978	29,275	India
Value £	147,922	105,204	40,547	83,704	75,538	114,143	
Value per ton £	1 0 11	1 0 4	1 2 3	1 12 3	1 10 10	3 18 0	
Tons	124,337	52,681	..	..	..	..	Russia
Value £	148,484	102,152	..	..	..	..	
Value per ton £	1 3 10	1 18 9	..	..	..	..	
Tons	227	8,321	49	100	805	4,362	United Kingdom
Value £	2,517	28,375	985	1,495	31,684	127,633	
Value per ton £	11 10 7	3 8 2	20 2 0	14 19 0	39 7 2	29 6 7	
Tons	..	1,300	5,141	30,563	44,512	82,974	Cuba
Value £	..	3,600	14,469	107,122	127,586	573,165	
Value per ton £	..	2 16 3	2 16 3	3 10 1	2 17 4	6 18 2	
Tons	..	..	..	1,244	7,163	9,680	Costa Rica
Value £	..	..	..	8,063	44,104	60,594	
Value per ton £	..	..	..	6 9 7	6 3 1	6 5 1	
Tons	..	..	..	10,498	5,202	5,607	Panama
Value £	..	..	..	55,369	33,983	54,635	
Value per ton £	..	..	..	5 5 6	6 10 8	9 14 11	
Tons	..	..	..	390	345	5,251	Mexico
Value £	..	..	..	1,478	2,040	33,199	
Value per ton £	..	..	..	3 15 9	5 18 3	6 6 4	
<i>United Kingdom</i> Tons	601,177	479,435	372,724	440,650	..	344,208	Principally from Russia, India, and Brazil.
Value £	1,295,113	1,001,654	1,180,758	2,322,400	..	..	
Value per ton £	2 3 9	2 1 9	3 3 4	5 5 5	..	..	

\* Compiled chiefly from Min. Res., United States.

TABLE 79.—IMPORTS OF MANGANESE ORE BY THE COMMONWEALTH, 1913-1919.\*

Country Importing.	Year.	Quantity.	Value.	Country Exporting.	Quantity.
New South Wales	1913	Tons. 174	£ 2,084	United Kingdom	Tons. 174
New South Wales	1914-1915	75	790	United Kingdom	75
New South Wales	1918-1919	3,120	14,960	{ East Indies (Java) New Caledonia ..	1,405 1,713
New South Wales	1919- June, 1920	2,619	11,848	New Caledonia ..	2,619

\* Official Statistics, Commonwealth of Australia.

TABLE 80.—LONDON QUOTATIONS FOR MANGANESE ORE, 1912-1914.\*  
(Values are per Unit of Metal.)

Year.	INDIAN AND BRAZILIAN.									RUSSIAN.					
	50 % Metal.			48 % Metal.			45 % Metal.			50 % Metal.			48 % Metal.		
	Max.	Min.	Mean.	Max.	Min.	Mean.	Max.	Min.	Mean.	Max.	Min.	Mean.	Max.	Min.	Mean.
1912 ...	s. d. 1 0½	d. 9½	d. 11½	s. d. 1 0½	d. 10½	d. 11½	d. 11½	d. 8½	d. 10½	d. 10½	d. 8	d. 9½	d. 10½	d. 7½	d. 9
1913 ...	1 0½	10	11½	1 0	9½	11	...	...	...	10½	8½	9½	10½	8½	9½
1914 ...	0 10½	9	9½	0 9½	9	9½	9	8½	9	8½	8½	8½	8½	8½	8½

\* C i.f. British ports. London Min. Jour.

Queensland prices in 1919 for small quantities of ore were £5 per ton, while 1920 prices for large quantities were about £3.40 per ton. New South Wales ore, evidently of low value, realised in 1919 about 15s. per ton and in 1920 about 19s. per ton. South Australian ore of good quality in 1919 averaged about £6 per ton, but in 1920 the high price of £16 11s. 9d. per ton was realised on 1,080 tons, probably for special chemical or electrical uses. In some American industries in 1917 the demand for high grade ore was so acute that up to £56 per ton was realised.

Commonwealth quotations for manganese ore have been very irregular owing to the demands being very small and supplies of domestic ore of medium grade abundant. There is, however, a demand for high grade ore in chemical, electrical and glass-making work, and no doubt ore could be marketed at high prices if grades of good quality were forthcoming.

With a better understanding of the industrial uses of manganese the producers in forwarding experimental consignments to dealers and others would be able to send the classes of ores required and thus obviate the disappointment often experienced through forwarding ore of very low grade, or ore rich in manganese but useless, on account of the absence of "available oxygen," to the glass-maker, and ore not rich in metallic manganese to the steel-maker.

Manganese ore for making ferro-manganese and spiegeleisen was not in demand within the Commonwealth before the war, but the manufacture of these alloys is now firmly established. The condition of purchase for such ores may be illustrated by reference to the conditions laid down in America by the Carnegie

TABLE 81.—MONTHLY QUOTATIONS FOR MANGANESE ORE, 1916-1920.  
(Basis, 50 per cent.)*New York. \**

	1916.	1917.	1918.	1919.	1920.
	Indian and Brazilian.	Indian and Brazilian.	Indian and Brazilian.	Brazilian or Domestic.	Domestic.
	Value per Unit.	Value per Unit.	Value per Unit.	Value per Unit.	Value per Unit.
	s. d.	s. d.	s. d.	s. d.	s. d.
January ..	2 8	3 1½	5 0	..	2 11
February ..	..	..	5 0	..	..
March ..	3 1	..	5 4	..	3 3
April ..	3 0	3 6½	5 2½	‡2 3½	3 3
May ..	3 4	3 10	**5 2½	‡2 1	3 0
June ..	3 4	4 2	5 4	‡2 3½	3 5
July ..	3 2	4 8	5 7½	\$2 8½	3 5
August ..	2 6	4 7	5 7½	\$2 1	3 1½
September ..	2 6	4 2	5 7½	\$2 3½	3 0
October ..	3 0	4 2	5 7½	\$2 0	2 8½
November ..	2 7	4 9½	5 7½	\$2 1	2 8½
December ..	2 10	5 0	5 7½	..	..

*London. †*

	Brazilian and Indian.	Indian.	Indian.	Indian.	Indian.
	¶ Value per Unit.	¶ Value per Unit.	¶ Value per Unit.	¶ Value per Unit.	¶ Value per Unit.
	s. d.	s. d.	s. d.	s. d.	s. d.
January ..	1 9	2 10	3 6½	3 0	3 3½
February ..	2 9	2 10	3 6½	3 0	3 6
March ..	2 7	2 10	3 6½	2 1	3 11½
April ..	2 7	2 10	3 6½	2 2	3 11½
May ..	2 6	2 10	3 6½	2 2	3 9½
June ..	2 4	..	3 6½	2 2	3 9½
July ..	2 4	..	3 6½	2 2½	4 1½
August ..	2 4	..	3 6½	2 1½	4 1½
September ..	2 4	..	3 6½	2 7	4 0
October ..	2 4	..	3 6½	2 9	3 9
November ..	2 8	3 4	3 6½	2 9	3 7½
December ..	2 5	3 5	3 6½	2 11½	..

\* Eng. and Min. Jour.

† Daily Coml. Reports, London.

‡ Domestic Ore.

§ Brazilian Ore.

¶ C.i.f. British Ports.

\*\* After 28th May, 1918, the price of *Domestic Ore* was fixed at 5s. 1d. per unit for 50% ore, and 5s. 5d. per unit for 54% and over.

Steel Company who have been encouraging the production of manganese in that country.

This company's schedule of prices shows that without any penalty they will take ore containing not more than 0.20 per

cent. of phosphorus, and not more than 8 per cent. of silica. In 1915 and in several previous years they were paying 11½d. per unit for 40-43 per cent. ore, 1s. per unit for 43-46 per cent. ore, 1s. 0½d. for 46-49 per cent. ore, and 1s. 3d. for over 49 per cent., the iron contents being paid for at the rate of 2½d. per unit. Every unit (per cent.) of silica in excess of 8 per cent. is penalised 7½d. per ton, and every 0.02 per cent. (*the unit*) of phosphorus over 0.02 per cent. is penalised 1d. per ton. Ore containing *less* than 40 per cent. of manganese, *more* than 12 per cent. of silica or 0.225 per cent. of phosphorus is not desired although sometimes taken. The above American prices are made favourable so as to encourage the local production of the ore.

English conditions of purchase generally impose a penalty of 7d. per ton for every unit of silica over 8 per cent. and a penalty of 1d. per ton for every 0.02 per cent. of phosphorus over 0.02 per cent. The percentages of iron are not mentioned but ore containing less than 45 per cent. of manganese is not required, 50 per cent. being generally specified. Another advice states that ores containing less than 40 per cent. of manganese, more than 0.12 per cent. phosphorus, and more than 15 per cent. of silica are either useless or difficult to sell in London.

Within the Commonwealth the Broken Hill Proprietary, whose steel works are at Newcastle, issues a memorandum of prices for ore delivered at Port Waratah, the basis being on ores containing not more than 8 per cent. silica and not more than 0.10 per cent. phosphorus, the prices being subjected to the following deductions:—For each 1 per cent. of silica above 8 per cent., 6d. per ton; for each 1 per cent. of iron above 4 per cent., 3s. 6d. per ton; for each 0.01 per cent. of phosphorus above 0.10 per cent., 1s. 6d. per ton, in addition to which all moisture above 1 per cent. is deducted. The following is this company's price list:—

Ore containing 40% and over of Man.	£3	7	0	per ton [= 1/8 per unit]
„ 43% „	£3	15	0	„ [= 1/9 „ ]
„ 45% „	£4	2	6	„ [= 1/10 „ ]
„ 47% „	£4	10	0	„ [= 1/11 „ ]
„ 50% „	£5	0	0	„ [= 2/- „ ]
„ 55% „	£5	10	0	„ [= 2/- „ ]
„ 60% „	£6	0	0	„ [= 2/- „ ]

Table 82 shows the average yearly quotations for ferro-manganese for both London and New York, and also for spiegeleisen for New York only. The figures indicate the official uniformity in London prices for ferro-manganese between the years 1916 and 1919, and the great variation in New York prices

between 1916 and 1920. In 1920 the great difference which existed between the two places suddenly disappeared and only a variation of about £3 existed.

Spiegeleisen prices in London have not been published, but in New York the quotations for a number of years are obtainable and are shown to vary from £7 5s. to £18 17s. per ton for alloy containing 20 per cent. manganese in the 1916-1920 period, the maximum prices being reached in 1917 and the lowest in the latter half of 1919. New York quotations for spiegeleisen having 16 per cent. and 30 per cent. manganese respectively, are also given in Table 82, but otherwise very little information is available.

TABLE 82.—ANNUAL QUOTATIONS OF FERRO-MANGANESE AND SPIEGELEISEN, LONDON AND NEW YORK, 1916-1920.

*Ferro-Manganese.*

Year.	London. †	New York. *	New York. *
	80%	80%	70%
	£ s. d.	£ s. d.	£ s. d.
1916..	24 5 0	51 12 0	..
1917..	25 0 0	71 15 0	..
1918..	25 0 0	Jan.-May 53 15 0	June-Dec. 52 0 0
1919..	25 0 0	April-Dec. 23 10 0	Jan.-Mch. 40 0 0
1920..	38 15 0	42 0 0	..

*Spiegeleisen.*

Year.	London. †	New York. *	New York. *
	16%	20%	30%
	£ s. d.	£ s. d.	£ s. d.
1916..	..	10 9 0	16 5 0
1917..	..	18 17 0	..
1918..	May-Dec. 15 14 0	Jan.-April 14 10 0	..
1919..	Jan.-Mar. 12 1 0	April-Dec. 7 5 0	..
1920..	..	15 0 0	..

\* Eng. and Min. Jour.

† Daily Commercial Reports, London.

Table 83 shows the monthly variation in ferro-manganese quotations in London and New York. The prices are usually based on a percentage of 80 per cent. of manganese, although in New York a 70 per cent. basis prevailed in part of 1918 and

1919. Prior to the London official price being fixed in 1916 the quotations reached £30 per ton, and after the three year and four months' period during which, evidently, the official price was fixed, the quotations rose to nearly double the official price.

### Future Considerations, &c.

The prospects of developing the manganese deposits of Queensland are controlled by many factors, of which perhaps the most important for future consideration in Australia are the uses of the metal in the manufacture of steel.

The manganese ores required in making ordinary alloys are those high in metallic manganese, the condition in which the metal occurs in the ores being only of minor importance. Only very little silica and mere traces of phosphorus are allowed

TABLE 83.—FERRO-MANGANESE QUOTATIONS, NEW YORK AND LONDON  
(MONTHLY VARIATIONS, 1916-1920).  
Average Values per Ton.  
*New York.\**

—	1916.	1917.	1918.	1919.	1920.
	80 %	80 %	80 %	70 %	80 %
	£ s. d.	£ s. d.	£ s. d.	£ s. d.	£ s. d.
January ..	27 1 0	36 9 0	52 1 0	46 17 0	29 3 0
February ..	42 18 0	52 1 0	52 1 0	39 1 0	..
March ..	65 2 0	78 2 0	52 1 0	30 4 0	44 5 0
April ..	88 5 0	78 2 0	52 1 0	80 % 25 10 0	46 17 0
May ..	75 10 0	91 2 0	70 % 52 1 0	23 19 0	45 2 0
June ..	57 5 0	88 10 0	52 1 0	23 8 0	46 17 0
July ..	46 17 0	91 2 0	52 1 0	24 9 0	49 9 0
August ..	39 1 0	86 3 0	52 1 0	22 18 0	44 5 0
September ..	35 8 0	78 2 0	52 1 0	20 18 0	42 14 0
October ..	34 7 0	75 10 0	52 1 0	19 18 0	36 9 0
November ..	34 7 0	54 13 0	52 1 0	20 18 0	35 8 4
December ..	..	51 10 0	50 0 0	23 19 0	..

\* Eng. and Min. Jour.

(Table continued)

*London.*†

(80% basis.)

*continued.*

—	1916.	1917.	1918.	1919.	1920.
	£ s. d.	£ s. d.	£ s. d.	£ s. d.	£ s. d.
January ..	22 10 0	25 0 0	25 0 0	26 10 0	27 0 0
February ..	25 0 0	25 0 0	25 0 0	26 10 0	29 5 0
March ..	28 0 0	25 0 0	25 0 0	25 0 0	38 0 0
April ..	31 0 0	25 0 0	25 0 0	25 0 0	46 0 0
May ..	30 10 0	25 0 0	25 0 0	25 0 0	46 0 0
June ..	30 0 0	25 0 0	25 0 0	25 0 0	46 0 0
July ..	25 0 0	25 0 0	25 0 0	25 0 0	..
August ..	25 0 0	25 0 0	25 0 0	25 0 0	..
September ..	25 0 0	25 0 0	25 0 0	25 0 0	..
October ..	25 0 0	25 0 0	25 0 0	25 0 0	..
November ..	25 0 0	25 0 0	25 0 0	24 0 0	..
December ..	..	25 0 0	25 15 0	23 0 0	..

NOTE.—The values are based on the mean of the highest and lowest quotations.

† Daily Commercial Reports, London.

to be present, although in making various kinds of alloys for special steels larger quantities of these two substances are not only permissible but essential.

Unusually high-phosphorus manganese ores, containing between 0.2 to 0.3 per cent. of phosphorus, would be valueless unless they are used with other manganese ores in making mangiferous pig iron, and even then the latter must be low in the uses of the metal in the manufacture of steel.

Ores for making ferro-manganese and spiegeleisen would be suitable if they contain not less than 46 per cent. of manganese, 4 to 7 per cent. of iron (which, however, is not a necessary constituent) not more than 7 per cent. of silica and not more than 0.07 per cent. of phosphoric acid (0.05 per cent. phosphorus). A typically inferior ore would contain, say, about 40 per cent. of metallic manganese, about 15 per cent. of silica, and about 0.1 per cent. of phosphoric acid.

The manganese ore required for available oxygen in glass-making and chemical work must be of good quality and 75 per

cent. of dioxide is essential. Dry electric cells require an ore containing 80 per cent. of dioxide and with only a very small percentage of iron (less than 1 per cent.), but while the quantity of ore required for this purpose is limited the price paid for it, as shown above, is the highest.

TABLE 84.—COST OF MAKING ONE TON OF FERRO-MANGANESE AND SPIEGELEISEN (GERMANY, 1914.)\*

FERRO-MANGANESE 80 % M <sup>n</sup> .			SPIEGELEISEN 29 % M <sup>n</sup> .		
Material.	Tons.	Value.	Material.	Tons.	Value.
		£ s. d.			£ s. d.
Iron ore .. ..	0·27	0 10 10	Iron ore .. ..	1·52	1 18 10
Manganese ore ..	2·43	4 17 6	Manganese ore ..	0·65	0 16 8
Coke .. ..	2·00	1 17 0	Coke .. ..	1·20	1 2 3
Limestone .. ..	0·06	0 0 2	Limestone .. ..	0·52	0 1 6
Labour .. ..	..	0 12 0	Labour .. ..	..	0 9 0
Total ... ..	..	£7 17 6	Total .. ..	..	£4 8 3

\* Eng. and Min. Jour.

In chemical work, particularly in the manufacture of permanganate of potash and soda, low grade ores can be used, but the removal of impurities in the manufacture greatly increases the cost of production. In glass-making too much iron oxide in the ore and too much manganese in any other form except the dioxide is very objectionable.

The costs of making ferro-manganese and spiegeleisen in England and America are not available, but in Table 84 is given the German costs of manufacturing the two metals in 1914.

Fairly large deposits of low-grade manganese ores are available in the State which have no present application, although in metallurgical works later on they might be utilised in the manufacture of spiegeleisen or manganiferous pig iron. For fluxing purposes also they would be valuable, but freights and working costs would be too high to enable their being worked successfully for this purpose unless near smelting works or close to railway or port, and then they must exist in very large quantities. High grade ore is not available in quantity, but the large Kandanga deposits with their supplies of medium-grade ore should become in future a very valuable asset in the steel-making industry.

At the present time we have to be satisfied with the use of manganese for glass-making purposes and, in a very small way, for chemical, electrical, and paint-making operations. Very little of the Queensland manganese, and apparently only a

medium quantity of New South Wales ore, is used in the steel works of the latter State. The quality of the product from both the States is, however, high enough for its utilization in steel-making, and the only impediment appears to be facilities for working, cost of transport, and cost of labour.

TABLE 85.—COSTS OF IMPORTED MANGANESE ORE. (In United States, United Kingdom, and Germany.)

—					United States.	United Kingdom.	Germany.
					£ s. d.	£ s. d.	£ s. d.
1911	..	..	..	..	1 8 0	1 6 0*	0 18 0*
1912	..	..	..	..	1 4 4	1 3 0*	0 16 0*
1913	..	..	..	..	1 4 6	1 3 0*	0 16 0*
1914	..	..	..	..	1 4 6	1 3 0*	..
1915	..	..	..	..	1 14 2	1 12 0*	..

\* Estimated.

The prospects of developing an export trade in manganese ore for steel-making are, however, distinctly pessimistic under present conditions of costs of freight and labour. The quantity of ore produced in Russia, India, and Brazil, shown in Table 73, and that imported into Great Britain and United States, shown in Table 78, clearly indicates the great sources and reserves of supply and where the great consumption takes place, all too far away to be influenced much by Australian production, while the value of the ore imported into the United States, the United Kingdom and Germany, shown in Table 85, can be taken as a fair gauge of what has to be done in the way of reducing costs before a trade can be established to compete with foreign trade even within the Commonwealth unless future conditions are to be considerably different from those prevailing before the war.

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# Article 9.—ARSENIC.

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# Article 9 - ARSENAL

## Section 1

The Arsenal shall be a public institution, established by the Government, for the purpose of manufacturing and supplying arms and ammunition to the armed forces of the State. It shall be managed by a Board of Directors, appointed by the Government, and shall be subject to the control and supervision of the Ministry of Defence. The Arsenal shall be responsible for the design, development, production, and maintenance of all arms and ammunition required by the armed forces. It shall also be responsible for the research and development of new arms and ammunition, and for the training of personnel in the manufacture and use of arms and ammunition. The Arsenal shall be financed by the Government, and shall be exempt from all taxes and duties. It shall be a public body, and shall be subject to the provisions of the Public Bodies Act, 1913.

## Section 2

The Arsenal shall be a public institution, established by the Government, for the purpose of manufacturing and supplying arms and ammunition to the armed forces of the State. It shall be managed by a Board of Directors, appointed by the Government, and shall be subject to the control and supervision of the Ministry of Defence. The Arsenal shall be responsible for the design, development, production, and maintenance of all arms and ammunition required by the armed forces. It shall also be responsible for the research and development of new arms and ammunition, and for the training of personnel in the manufacture and use of arms and ammunition. The Arsenal shall be financed by the Government, and shall be exempt from all taxes and duties. It shall be a public body, and shall be subject to the provisions of the Public Bodies Act, 1913.

## Article 9.—ARSENIC.

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### Queensland Localities.

Arsenic in the form of Mispickel, its principal natural compound, has been found in a vast number of localities in Queensland, and in a great variety of mineral deposits, but not in such quantities that any single deposit can be said to be abnormally large.

In the Stanthorpe Tinfield the mispickel is commonly associated with tinstone, and in the mines at Sundown on this field a considerable percentage of the tin concentrate is made up of mispickel, while the lodes at Jibbinbar on the same field also contain it in varying quantities. Latterly the Jibbinbar area has developed into an arsenic-producing locality, and a State mine and works have been established there.

In the Burnett District, particularly at the Auburn River and in numerous places in and about the mines of Mount Biggenden and Mount Shamrock, mispickel commonly occurs with gold, bismuth, and copper ores. At the Auburn Falls mine the mineral is in large lodes associated with gold, and at the Shamrock mine the lower levels have exposed a mineralised zone largely made up of mispickel. At Biggenden the mineral is always associated with bismuth in an irregular magnetite deposit and also in an adjacent intrusive rock.

In the Cooktown District a mispickel lode has been discovered a few miles from the railway near Battle Camp, and numerous occurrences have been recorded at the Annan mines of mispickel in association with tin ore, the same mineral also being found on the Palmer Goldfield in lodes containing gold. On the Chillagoe and Herberton fields it is found with copper, tin, gold, silver, lead, wolfram and molybdenite, extensive surface deposits of clean mispickel being reported to occur on the Dry River, with smaller outcrops at Emuford and Stannary Hills.

Other arsenic deposits occur at Mount Osman, known also as the "Pinnacles," four miles north-easterly from Boonmoo Railway Station, and some consideration has been given to the working of them on a large scale. The lodes of the Norton Goldfield contain large quantities of mispickel, but the mines which were worked for the recovery of the gold in the ore have

been abandoned for many years. Recent examinations, however, show that large quantities of arsenical ore await development. The Ravenswood field also contains numerous lodes in which the gold is associated with mispickel and other minerals.

Deposits containing arsenic in association with other metallic minerals are known about Pikedale, Eidsvold, Mount Perry, Stanhills, Kilkivan, Barmundoo, Glenbar, Gebangle, Bompa, Hodgkinson, Etheridge, Coen, Dry River, Starcke, Sellheim, Mount Barker, and several other places, many of which no doubt could be made to yield quantities of arsenical by-products during the treatment of the minerals for gold, silver, copper, and other metals. (*See Queensland Mineral Index for references to these localities.*)

### Other Localities.

Within the Commonwealth many localities on the numerous mining fields are known where arsenic occurs either as distinct lodes of mispickel or in association with gold, copper, lead, wolfram, molybdenite, or tin. In Victoria the gold-bearing lodes at Bethanga, Cassilis, Stawell, Bendigo, and Ballarat contain mispickel, but only the mineral which is also gold-bearing is considered sufficiently valuable to be used for the extraction of arsenic. Large bodies of mispickel are unknown. In New South Wales arsenic-bearing minerals are to be found on several of the mining fields, occurrences being recorded at the Conrad Mine at Howell where a large lode of mispickel was worked for arsenic some years ago, and at Lucknow where mispickel has been found associated with rich gold deposits. The Talwong Mine on the Shoalhaven River contains a large permanent lode of copper-tin ore in which quantities of arsenic are said to occur.

In South Australia deposits of mispickel have been exposed in the Taliska and Glen Bar mines near Victor Harbour, and several years ago the Preaminna mine near Callington was worked principally for arsenic, the demand for which, however, was then so small that the mine was abandoned. Other localities where arsenic has been noted include Woodside, Mannahill, and Kangaroo Island.

In Tasmania mispickel occurs abundantly at the Mount Bischoff mine in association with tin, the mineral also occurring at the Colebrook mine at Dundas, the Magnet mine at Magnet, and at Mount Lyell and other localities.

In Western Australia mispickel carrying gold is to be found at Coolgardie, Kimberley, and Yilgarn, the Transvaal and Greenmount mines on the last mentioned field containing it very plentifully.

In New Zealand it is recorded that Native Arsenic in association with gold and quartz occurs at the Kapunda Mine at Coromandel, the lode some years ago being considered to be an important one. Mispickel occurs on the Reef-ton Goldfield and many other localities in association with gold-bearing ores.

In Spain arsenic is associated with cobalt, gold, and mercury ores; mispickel also occurring as large deposits unassociated with any other minerals. In Austria arsenic is found with mercury, while in France it mostly occurs as deposits of the native metal. In Italy, Portugal, Turkey, Norway, and Sweden it is found in lodes made up of iron pyrites and mispickel, and in some cases in association with cobalt or with small quantities of gold, while other countries in which its occurrence has been recorded, and in some cases in which productions have been made, include Japan and China.

In the United States it is found with lead, tin, copper, and gold, and also with quartz without any other industrial metal present. In Canada it occurs with gold, nickel, and cobalt.

In England great quantities of arsenic come from the copper and tin mines of Cornwall and Devon, while in Germany large supplies are obtained from the lead mines at St. Andreas-berg in the Oberharz, and from the silver and tin mines of Eryzeberge near Freiberg. It is from England, United States, Germany, and Canada that most of the arsenic supplies of the world are now obtained.

### Geological Notes.

Arsenic in Queensland occurs in granite, diorite, porphyry, garnet rock, greisen, and sedimentary rocks, and in association with copper, tin, gold, silver, lead, zinc, bismuth, antimony, tungsten and molybdenum. In many instances its occurrence with gold, bismuth, wolfram, and tin ores has been a disadvantage in their treatment, its presence in bismuth ores particularly being objectionable on account of the difficulty in separating the two metals either by concentration or by metallurgical treatment.

In some mines the presence of arsenic is indicative of high values in other metals, but on the other hand sometimes the percentages of the valuable metals become very small where the percentage of arsenic is high.

Outcrops of arsenical ores in appearance vary with the character of the associated metals, and as iron is so often an associated metal the outcrops resulting from the decomposition

of arsenical lodes would generally be ferruginous. The outcrops also contain scorodite, the greenish arsenate of iron, as an intermediate change from the sulpharsenide of iron to the oxide of iron. The arsenates of other metals such as copper and lead are also formed in the same way although of rarer occurrence.

The Jibbinbar arsenic lode being worked at the State mine is in places about twelve feet thick, but two feet is considered a good working average width. The ore is fairly clean mispickel with traces of copper pyrites, and is contained in a quartz gangue, the country rock being granite and altered sedimentary rocks, the lode passing from one into the other. An analysis of the clean ore, specially selected, shows that the mineral is mispickel, its composition being as follows:—Arsenic, 45.0 per cent.; sulphur, 18.5 per cent.; iron, 33.2 per cent.; copper, cobalt, nickel, bismuth, antimony, gold, and silver all *absent*. A general bulk sample of the ore was found to have the following composition:—Silica, 57.9 per cent.; arsenic, 13.8 per cent.; sulphur, 6.6 per cent.; iron, 15.1 per cent.; copper, 0.05 per cent.; bismuth *trace*; tin, nickel and cobalt *absent*; gold *absent*; silver, a few dwts.

The Biggenden bismuth mine, which has not been working for some years, contains a very large irregular lode of magnetite, in places containing bismuth only, in other portions bismuth with mispickel and mispickel without bismuth. The portion worked has been opened up for its bismuth contents, and the 10 to 20 per cent. of mispickel in the saved bismuth concentrate has always been a nuisance. Where the arsenic occurs unassociated with bismuth the quantities are said to be large, but definite information on the point is wanting.

The Boonmoo arsenic lode in the Chillagoe district is considered to be a very large deposit and very rich in arsenic (although this wants confirmation) and is situated in a belt of "porphyry."\* Associated minerals are native bismuth, wolfram, gold and silver, and the quantity of arsenic present, estimated as arsenious oxide, is said to be about 17 per cent.

The Norton arsenic-gold lodes are those most promising in the Port Curtis district.† They are occasionally in the form of fissures but usually as "formations" containing mispickel, galena, blende and copper pyrites, of which two or three are sometimes closely associated. One large lode is estimated to contain 15½ per cent. of arsenic. The country rock is a fine-grained biotite granite.

\* W. Grant Taylor. See Bibliography.

† Arsenic and its Occurrence in Southern Queensland. By Dr. H. I. Jensen, Q.G.M. Jour., Vol. 19 (1918); Pt. 1, pp. 445-461; Pt. 2, pp. 503-508 (contains references to Norton).

The Sundown lodes in the Stanthorpe district are tin-copper-arsenic deposits, sometimes with copper absent, and occasionally with wolfram and a little silver and gold present, these minerals occurring in irregular jointings, or as impregnations close to the joints, in much altered sedimentary rocks. Granite is in the neighbourhood, and the sedimentary rocks are intruded by a system of diorite dykes and by two huge quartz-porphyry dykes. The arsenical ore in some of the mines reach a percentage of over 30, and hand dressing will bring this up to 45 per cent. or more, although in some of the lodes the percentage of arsenic is about 10.

### Mineral Notes.

Many minerals contain arsenic as one of their essential constituents; in others it is only an accessory element. In several copper, nickel, cobalt, bismuth and lead ores and in almost all iron ores arsenic occurs in small quantities, and traces of it have been found in mineral waters, and even in sea water.

Nearly all minerals with arsenic in their composition will fuse or volatilize on heating, at the same time giving off a characteristic garlic odour and forming a white incrustation if heated on charcoal. When struck with a hammer this odour is given off, and in working the mineral in the mines the smell is also very pronounced.

In metallurgical work mispickel is the principal arsenical mineral, others of minor importance being realgar, orpiment, and native arsenic. These are briefly described below, and a classification based on chemical composition is given of the various other minerals which contain arsenic as an essential constituent.

*Mispickel* (syn. Arsenopyrites, Arsenical Pyrites—in part).—Colour is silver-white or steel-grey; lustre, brilliant on crystallized faces; brittle. Hardness, 5.5—6; specific gravity, 6.1. Composition—sulpharsenide of iron (46 per cent. of arsenic) but sometimes grading into lollingite, the arsenide of iron; often cobaltiferous; sometimes auriferous. When heated before the blowpipe forms a white coating on charcoal and emits arsenical and sulphurous fumes.

*Realgar* (syn. "Red Arsenic," "Red sulphur").—The mineral is orange-red, resinous and sectile, and has a bright non-metallic lustre. Hardness, 1.5—2; specific gravity, 3.5. Composition—arsenic sulphide (70 per cent. arsenic). Has the same blowpipe reactions as mispickel, except that no iron-bearing residue is formed.

*Orpiment* (syn. King's Yellow).—The colour of the mineral is lemon-yellow, otherwise it resembles realgar in its physical properties. Hardness, 1.5—2; specific gravity, 3.5. Composition—arsenious sulphide (61 per cent. of arsenic). Has the same blowpipe character as realgar.

*Native Arsenic* is tin-white in colour, has a dark-grey tarnish and generally occurs massive with a fine-granular fracture. Hardness, 3.5; specific gravity, 5.6. Composition—arsenic, with traces of iron, antimony, bismuth, gold and silver. On charcoal volatilizes without fusing when heated, forming a white coating and emitting a garlic odour. Antimony is sometimes present in sufficient quantity to constitute the natural alloy allemontite, which contains 65 per cent. of arsenic, and occasionally the amount of bismuth present with the arsenic is sufficiently high to constitute arsenical bismuth.

*Arsenical Mundic* is a term used by miners to include any pyritous minerals giving off the smell of arsenic when being worked. The odour is decidedly unpleasant and quite distinct from the smell of sulphur.

### Principal Arsenic-bearing Minerals.

Native metals and alloys—*Native Arsenic*; *Allemontite*, *Arsenical Bismuth*.

Oxide—*Arsenolite* (white arsenic).

Sulphides—*Realgar* (red); *Orpiment* (yellow).

Arsenides—*Lollingite* (syn. Leucopyrites, Arsenosiderite, Arsenical Pyrites—in part, Prismatic Arsenical Pyrites), contains iron, &c., and merges into Mispickel; *Niccolite* (syn. Copper Nickel) contains nickel, without copper; *Smaltite* (syn. Grey Cobalt Ore); *Chloanthite* (syn. White Nickel Pyrites); *Domekyite* (syn.—Arsenical Copper).

Sulpharsenides—*Mispickel* (syn. Arsenopyrites, Arsenical Pyrites—in part); *Gersdorffite* (syn. Nickel Glance); *Cobaltite* (syn. Cobalt Glance, Arsenical Cobalt); *Tennantite* (syn. Grey Copper Ore—in part); *Sartorite* and *Dufrenoyite*, both contain lead; *Glaucodot*, contains cobalt and iron; *Proustite* (syn. Ruby Silver Ore).

Arsenates—*Scorodite* and *Pharmacosiderite* (iron); *Pharmacolite* (lime); *Olivenite* and *Liroconite* (copper); *Mimetite* (lead); *Annabergite* (Nickel Bloom); *Erythrite* and *Clinoclasite* (Cobalt Bloom).

In addition to the above there are perhaps 100 more-or-less well-defined arsenic-bearing minerals containing such elements as iron, copper, cobalt, nickel, antimony, lead, bismuth, platinum, gold, silver, sulphur and oxygen, some being simple compounds, while others such as the sulph-arsenides, sulph-arsenites, and sulph-arsenates are very complex.

### Metallurgical and Chemical Notes.

The metallurgical treatment of arsenical ores consists primarily in the production of metallic arsenic, arsenious oxide, realgar, and orpiment. From these products a number of secondary compounds are developed by chemical processes and variously used in the manufacture of pigments, insecticides, dyes, alloys, poisons, fluxes, fireworks, &c., &c.

Most of the arsenic of commerce is produced as a by-product in the treatment of ores of tin, copper, and cobalt, although nickel, gold, silver, lead, mercury and iron ores also yield considerable quantities. Many old abandoned mines, working on tin and copper, furnish arsenic from the accumulated waste heaps, while another source of supply, to a limited extent, is the slimes in the electrolytic treatment of blister copper, this metal usually containing from 1 to perhaps 5 per cent. of arsenic. Mispickel is also used at times solely for its production.

In England the arsenic from the Cornwall and Devon mines is generally produced in the treatment of ores containing tin and copper, and to a limited extent also from bismuth. Small quantities are obtained from mispickel unassociated with any other mineral, and it is also collected from waste heaps.

In Germany the lead works of Freiberg produce white arsenic, realgar, and orpiment, the ores being brought from mining areas away from this centre. In Austria it is a by-product in the distillation of mercury, the compound produced being realgar, while in Spain it forms a by-product from the treatment of gold ores and also as the principal product from the roasting of mispickel.

In Portugal the arsenical ores are treated primarily for arsenic, and in Italy orpiment is a product from the refining of crude sulphuric acid containing arsenic, gold in traces also being obtained from the pyritic ore from which the sulphuric acid is made.

In the United States the oxide is produced from lead, gold and copper ores, and in Canada it was once a product from the

treatment of nickel-cobalt ores and from gold-bearing quartzose ores, but is now generally a direct product from mispickel.

In the above mentioned localities nearly all the arsenic is made from mispickel mixed with other ores, the sulphides, arsenides, and other sulpharsenides being of subordinate importance, although a new source for the oxide has been found in the treatment of iron pyrites mixed with mispickel in the manufacture of sulphuric acid. Processes are now perfected whereby the arsenic is recoverable as a by-product from the sulphurous fumes, and in future very large quantities no doubt will be made in this way.

Within the Commonwealth there are now several works established for the manufacture of white arsenic from mispickel, a modern plant being that recently put into operation at Jibbinbar, near Stanthorpe, where large quantities of arsenic are now being produced by the State and where ore is treated containing no realisable metals, the works depending on white arsenic as the sole product.

*Realgar*, or red arsenic sulphide, is made by subliming at a red heat the arsenic and sulphur from a roasting charge made up of mispickel and iron pyrites, or a mispickel mixed with sulphur. The process is in two stages, an outline of which is given on page 310. Mispickel and iron pyrites together in a lode would be a favourable condition for the occurrence of ore from which to manufacture this product. It is also made by the sublimation of arsenious oxide in the presence of iron or lead sulphide. This "red sulphur," as it is called, has an orange tint, and forms a useful paint pigment, also being used as an ingredient in pyrotechnic compositions for giving white Bengal fire and other coloured fires. It is also a constituent of various mixtures which were once commonly used for removing hair from hides in tanning operations.

*Orpiment*, or King's Yellow, is not a sulphide like the mineral of the same name but consists of arsenious oxide sublimed with a little sulphur. The operations are somewhat similar to those in the manufacture of realgar, and the two products are at times manufactured alternately in the same metallurgical plant.

Chemical orpiment, which is a true sulphide, may also be produced from a hydrochloric acid solution of arsenious oxide by forming a precipitate with sulphuretted hydrogen, and also from the residues in the refining of commercial sulphuric acid. In the latter case the arsenic is contained in the pyritic ore used in furnishing the sulphur for the acid, sometimes the percentage

of arsenic in the sulphuric acid being considerable. There is an English record of several thousand persons being poisoned, some fatally, by drinking malt liquors containing arsenic derived from the impure sulphuric acid used in connection with their manufacture. Very little use is now made of the compound although at one time it was very popular as a yellow pigment. It is no doubt poisonous, and is also unstable, and much more desirable compounds such as lead chromates and coal-tar colours have taken its place in paints.

*Arsenite of Potash* is made from arsenious oxide, tartaric acid, &c., and is the basis of a green pigment or stain used in paper-making. It also forms part of an anti-fouling composition used in painting ships' bottoms.

*Alloys.*—Arsenical Lead is used in the manufacture of shot, the proportion of arsenic to lead being less than 1 per cent., but antimony is often used instead. This alloy is made by fusing the arsenic either as a metal, oxide or sulphide with metallic lead, the shot being formed by passing the molten alloy through sieves or cullenders and dropping it from a great height into water, the arsenic when in the right proportion preventing the molten shot from shrinking irregularly or from becoming elongated while falling. An alloy of 49 per cent. of copper, 49 per cent. of silver, and 2 per cent. of arsenic is the formula of a Britannia metal, once commonly made into table ware, but now discarded on account of its poisonous effects. Alloys of silver and arsenic and of copper and arsenic are also manufactured although their application is very limited. Metallic arsenic is used in giving a bronze colour to brass, and 0.02 per cent. added to Muntz metal enables better castings being made than from metal which is without arsenic.

*Metallic Arsenic.*—The production of metallic arsenic is carried on in galley furnaces, the ore being distilled in tubes and pots, with attached receivers for the condensation of the arsenic. The metal may be either crystalline or amorphous, both forms being produced from mispickel or lollingite, the residue consisting of iron sulphide, silica, and other metallic and non-metallic impurities. This method is the only effective one of obtaining a bright metal, the reduction of the oxide by other processes only producing the arsenic as a grey crystalline powder.

An electric furnace process has also been invented in which the arsenic contained in mispickel is distilled, the iron being formed into a matte as ferrous sulphide. Reference to this is made under "Furnace Operations."

Metallic arsenic is of a steel grey colour, and rapidly tarnishes when exposed to the air. In chemical reactions it generally takes the part of an acid, as in arsenates, and rarely as a base, as in sulphides and oxides. It is electrically positive and is a good conductor of both heat and electricity.

*Arsenious Oxide.*—The methods generally adopted in making this trioxide, or white arsenic as it is called, consist in roasting the ores in revolving, muffle or reverberatory furnaces with excess of air, the oxide being volatilized and then condensed in flues and chambers, the furnace residues consisting of iron sulphide, oxide, or arsenate, and various unvolatilizable impurities. These impurities may be tin, copper, gold, silver, nickel, and cobalt, and the recovery of one or more of these metals in the form of compounds free from arsenic is sometimes the primary object of the roasting operations. In the roasting of the ores very little fuel is required, the combustion or oxidation of the arsenic producing almost sufficient heat for the purpose.

White arsenic has a slightly sweetish astringent taste, more pronounced in the glassy or crystalline form than in the powder, and as it is only slightly soluble the taste is not immediately perceptible—hence the cases of accidental poisoning from taking it.

The solubility of arsenious oxide in water and other solutions is as follows:—Hydrochloric acid, 1 in 6; potash solution, 1 in 11; glycerine, 1 in 8; boiling water, 1 in 20; solution of carbonate of soda, 1 in 40; cold water, 1 in 100; alcohol, 1 in 500 (approximate).

Arsenious oxide is used for a great variety of purposes, principally as an ingredient in the manufacture of pigments, as a flux in glass-making, as one of the ingredients in most cattle dips and in many sheep dips, in prickly-pear and other plant destroyers, in rat and white-ant poison, and in various other poisonous compounds. In the manufacture of pigments and dyes it is mixed with inorganic compounds and coal-tar products to produce green, yellow, red and other colours.

Arsenious oxide is the most important industrial compound of arsenic, and further references will be made to it under “Uses of Arsenic Compounds” and “Furnace Operations.”

*Arsenic acid* (pentoxide) or white arsenic acid is made by adding four parts of arsenious oxide to three parts of nitric acid, the latter oxidizing the former. When made commercially most of the nitric acid is recovered and used again. In the manu-

facture of the arsenates used as poisons most of this acid is imported, but firms are now making it within the Commonwealth, and it will be only a matter of time when the whole of our requirements for the making of plant poisons from this acid will be locally supplied. Arsenic acid is also used as a spray insecticide by mixing it with sulphuric acid but no information is available concerning the proportions of the two acids in the mixture. This insecticide has only recently been put on the market, although reports are favourable regarding its efficacy in insect destruction. The company manufacturing the insecticide makes its own arsenic acid and a factory is established in Sydney. The discovery that arsenic acid is useful as a pear poison is due to Dr. Jean White, who investigated its properties and advocated its use.

Arsenic acid is used in making yellow, magenta or rose-aniline and other aniline dyes, and recent experiments in Queensland in prickly-pear destruction have shown that this oxide is more soluble and therefore more effective than the trioxide as a plant poison.

*Arsenious Chloride* is a colourless oily liquid which on exposure evaporates quickly and gives off heavy white poisonous fumes. It is made by burning powdered arsenic in chlorine gas or by distilling arsenious oxide with concentrated sulphuric acid and common salt. It is very efficacious in destroying prickly-pear, and has recently been experimented with in the destruction of flying foxes in a camp where they rest during the day. The results were not satisfactory, however, the heavy gas when discharged remaining close to the ground and failing to reach the animals where they were hanging from the high branches of trees. During the war large quantities of arsine chlorides were used as a poison gas and its inclination to keep close to the ground was an advantage when being used for this purpose.

*Arsenite of Soda* is a compound resulting from the action of either caustic soda or carbonate of soda on a solution of arsenious oxide, and is the principal tick-poisoning ingredient in all cattle dips. It is also used extensively for the destruction of grasshoppers, white ants, &c., but, unlike other arsenites, it has a very destructive action on plant tissue.

Arsenite of soda is made in the same way as Kedzies arsenate of lime, but the lime is omitted, and by varying the proportions of soda and arsenic either a neutral or acid arsenite is formed. The fumes arising from the reaction are very dangerous and care must be taken not to inhale them. This compound is

manufactured in Australia in large quantities, some of which is exported to South Africa.

*Arsenate of Soda* is an important salt made with arsenic acid and soda. It is employed extensively in calico printing, and now utilized very largely in making an important insecticide. In calico printing it is applied to the parts of the fabric where the dyes are not to be fixed by mordants, and for this purpose it is used as a paste on printing blocks. Subsequently the unfixed dyes and the arsenate of soda are washed out, the latter being recovered and again utilized. The insecticide made from this salt is arsenate of lead, reference to which is given further on.

*Arsenate of Potash* (Fowler's Solution) is a medicinal compound made from the nitrate or carbonate of potash and arsenious oxide. Soda sometimes replaces the potash.

*Arsenate of Lime* was a by-product in the making of aniline dyes, but is now prepared by mixing solutions of potassium or sodium arsenites with calcium chloride, or arsenious oxide with calcium hydrate (lime). A standard U.S.A. analysis for this compound when used as an insecticide is as follows:—(1) Arsenic pentoxide, not less than 40 per cent. (2) Water soluble pentoxide not more than three-quarters of one per cent. (3) Density not less than 80 or more than 100 cubic inches to the pound. It is made by mixing in boiling water one part of arsenious oxide to two parts of freshly slacked lime, and then adding additional lime. By an adjustment of the proportions of the ingredients either the neutral or acid arsenate can be made, the former being the more useful as an insecticide. It can also be employed as a dust spray, and also as an insecticide to mix with a fungicide such as "lime-sulphur" or "soluble sulphur," while its cheapness compared to arsenate of lead, for which it can be substituted almost for all purposes, specially recommends it.

Kedzie's Arsenate of Lime is made by boiling sal-soda (washing soda) in water with arsenious oxide, in the proportion of 8 pounds of soda, 2 pounds of arsenic, and 2 gallons of water. To this lime is added when the liquid is ready for spraying.

The absence of water-soluble arsenic pentoxide is considered to give the arsenate of lime an advantage over most other arsenical insecticides, as the presence of this pentoxide is destructive to leaf issue. It is specially valuable in the destruction of the cotton-boll weevil and other mandibulate insects. Sulphide of lime with arsenate of lime forms a combined insecticide and fungicide.

*London Purple* is another arsenic-lime compound formed as a by-product in making aniline dyes, and was once a commonly used insecticide. It contains free arsenious oxide, and in consequence lime has to be added when using it.

*Arsenite of Copper* is made with arsenious oxide, potassium carbonate and copper sulphate. The potassium carbonate (or ammonia) is necessary in the chemical reactions, although potassium does not enter into the composition of the salt. It was formerly used, at Scheele's Green, in calico printing and in colouring wall papers, but at the present time has a very limited application. This compound when used in calico printing is entirely removed after its function has been performed, and its recovery from waste dye solutions has been the subject of much consideration.

*Aceto-Arsenite of Copper* is made with verdigris (basic acetate of copper) and arsenious oxide in boiling water, or with acetate of copper arsenite of soda and acetic acid, various methods of preparation being practiced. As a pigment it is known both as *Paris Green* and *Emerald Green*, and under the former name it is used as an insecticide. Many other green pigments contain arsenic, and some of the finest tints are made by combining copper sulphate, caustic soda, arsenious oxide and acetic acid, and sometimes with lime or barytes in addition, details of which are given in "A Treatise on Colour Manufacture."\* A process has been patented for the making of the aceto-arsenite of copper, in which a solution of calcium acetate and arsenious oxide is electrolysed with a copper anode, the compound being deposited as slimes.

For the destruction of insects, Paris Green is used suspended in water (one pound to 150 gallons) or in a dry state mixed with flour, starch, plaster-of-paris, &c. In the latter condition it is destructive to grasshoppers when dusted on pollard mixed with syrup, or on chaff made of lucerne or other green fodder, but latterly has been superseded by other arsenical compounds. In using it for spraying trees it must be mixed with an equal weight of lime to prevent the destruction of the foliage.

*Arsenate of Lead* is made by boiling in 120 gallons of water 11 ounces of lead acetate (or nitrate) with 4 ounces of the arsenate of soda previously referred to or its equivalent of arsenic acid. This di-plumbic arsenate is now a very important insecticide, and to a great extent replaces other compounds of arsenic for this purpose, specially for the destruction of codlin moths and caterpillars. Its efficacy as a spray seems to depend principally on its covering power, and some official observations

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\* See Bibliography.

have been made showing that the fineness of the particles of the compound has a very important bearing on its utility in this respect. Good brands of the poison when mixed up and suspended in water show that only 60 per cent. will settle after being fifteen minutes in water, while with inferior brands about 80 per cent. will fall down in about five minutes.

A number of analyses of commercial samples of arsenate of lead are given in Table 86 to show the proportions of moisture, arsenic and lead. Some are in the form of solutions, others in powders or pastes, so that in determining values, allowance must be made, for the amount of water contained in them. Table 87 has been calculated on the preceding one, and the percentages given are those of the dry ingredients only.

The results show that these commercial compounds vary between 60 and 65 per cent. of lead oxide and between 28 and 33 per cent. of arsenic oxides. Both the powders and pastes are good, but the former are considered to be more reliable in not being subject to chemical change during hot weather. Unlike Paris Green, arsenate of lead causes very little damage to foliage, but the former is very much cheaper, and as the liability to injury is easily overcome by spraying, it is still largely used.

Arsenate of lead is also used as a powder or dust mixed with lime, clay, starch, &c., which act as "spreaders." It is also used in various preparations in the destruction of ladybirds, weevils, caterpillars, &c., and its use in destroying the codlin moth in apples is noteworthy.

TABLE 86.—COMPOSITION OF SOME COMMERCIAL ARSENATES OF LEAD.

(With Moisture.)

	Moisture per cent.	As <sub>2</sub> O <sub>5</sub> per cent.	PbO per cent.	Water Soluble As <sub>2</sub> O <sub>5</sub> per cent.
1. (solution) ..	44.5	16.6	34.1	0.13
2. (powder) ..	0.15	31.7	60.2	0.14
3. (solution) ..	45.1	16.6	32.7	0.13
4. (paste) ..	0.42	30.1	62.6	0.09
5. (powder) ..	0.16	33.0	59.0	0.11
6. (powder) ..	0.08	30.7	61.6	0.09
7. (solution) ..	54.7	14.5	28.3	0.13
8. (solution) ..	46.2	15.8	33.2	0.16

*Arsenate of Zinc* is made by melting together white arsenic and zinc, or by combining arsenite of soda with zinc sulphate in the proportions of about 1 to 2.3. As an insecticide its action is that of arsenate of lead but it has several points in its favour.

*Arsenic and Oil Compounds.*—Arsenic compounds in some cases can be intimately incorporated in certain oils of the benzene series containing phenylic and cresotic bodies which have been combined with sulphonic acid in a process of sulphonication. These arseno-sulphonic oils resemble saponified oils (soaps), and combine with water in all proportions, their arsenic contents being operative in insect destruction. They also have some fungicidal value and may be so modified that they become specially useful for this purpose.

These compounds are of special and growing importance and are available for both mandibulate (chewing) and haustellate (sucking) insects, and it would appear that in conjunction with certain precautionary measures they may be useful in controlling the blowfly of sheep and other stock ectozoa such as lice, ticks, and fleas. (Tryon.)

TABLE 87.—COMPOSITION OF SOME COMMERCIAL ARSENATES OF LEAD.  
(After Removal of Moisture.)

	As <sub>2</sub> O <sub>5</sub> per cent.	PbO per cent.	Water Soluble As <sub>2</sub> O <sub>5</sub> per cent.
1. . . .	30.2	62.0	0.23
2. . . .	31.7	60.3	0.14
3. . . .	30.2	59.6	0.23
4. . . .	30.2	62.8	0.09
5. . . .	33.0	59.1	0.11
6. . . .	30.7	61.6	0.09
7. . . .	32.0	62.5	0.29
8. . . .	29.3	61.8	0.29

### Furnace Operations.

*Arsenious Oxide.*—The furnaces used for roasting the arsenical ores vary much in character. Some are the simple square reverberatory type, others are reverberatories with mechanical rabblers, a third group being rotary calciners, each having modifications in the arrangement for firing, feeding, or

stirring. Merton and Edward's furnaces are two variations of the ordinary mechanical reverberatory type and each has its merits, either one or the other being used in general practice in Australia, not only for arsenic roasting but for many other purposes. The Merton furnace is an economical roaster, having three hearths superimposed, and sometimes with a rotary hearth in addition if clean residues are specially desired, the rabbling being done by chains with attached blades passing longitudinally through the furnace.

The Oxland rotary furnace is a brick-lined cylindrical iron shell about 6 feet in diameter, 50 feet long, and set nearly horizontal.\* The internal construction, a Rothwell modification, is a projection of long tiles fixed longitudinally and openly, and meeting at the centre, thus dividing the furnace into four long quadrants, a section of which would be a cross. The Brunton furnace, a common English type, is a fixed circular furnace about 15 feet in diameter, with a rather flat cone-shaped revolving hearth. The ore is fed through a central hopper and is evenly distributed on the revolving hearth by fixed rakes attached to the roof, the heat being supplied from two fire grates on opposite sides of the furnace. A modification of this furnace by Blake, which dispenses with direct firing and uses superheated air instead, is said to effect very rapid combustion of the sulphur fumes.

The Cotton cubical furnace, an Australian type, has a movable hearth mounted on a truck, the ore being heated with a producer gas containing carbon monoxide and hydrogen, the arsenic being volatilised without oxidation. The arsenic fumes are sent into a condensing chamber into which jets of water and cool air are driven, the arsenic being rapidly oxidised and thrown down as a wet deposit. The process dispenses wholly or partly with the troublesome flues and chambers.

In the furnace treatment of arsenical ores it seems that a temperature of about 1,300 degrees Fahr. is advisable where the heat is generated, about 1,200 degrees Fahr. where the ore receives its final heating, and about 1,000 degrees Fahr. where it is first delivered on to the hearth. Along the flues the deposition of arsenic begins to take place where the temperature is about 350 degrees Fahr., 90 per cent. of the deposit condensing between this degree of heat and 300 degrees Fahr.

Trouble in roasting is frequently produced when too much sulphide ore is present in the roast. The sulphur exhausts the supply of oxygen before all the arsenic is oxidised, and unless

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\* Illustrated in Thorpe's Dictionary of Applied Chemistry, 1912. Vol. 1, p. 297.

some means are introduced to provide additional air some of the arsenic will remain in the furnace residue. It therefore becomes advisable in making arsenious oxide to use ores as free as possible from other sulphides.

Mixing the furnace gases with cool air to reduce the temperature to 250 degrees Fahr. causes the condensation to become rapid, and a system in which this operation takes place is said to require very short flues. The dust is collected by filtering through bagging, or wire netting (Rooesing wires), or collecting on plates of sheet iron (Fraudenberg plates). It is said that by further cooling the gases and then subjecting them by mechanical means to alternate expansion and compression any arsenic remaining in the gases is condensed to misty oxide, which either falls to the floor or is collected by the bagging, wires, or plates.

The flues and the collecting chambers attached to the various types of furnaces vary considerably in shape, length, and arrangement, and all sorts of devices are introduced to precipitate the arsenious oxide from the escaping gases, perhaps the latest being an invention by Cottrell to send the fumes and dust through a series of plates and rods electrically charged, which is said to rapidly settle the dust and condensed fume. The roasting furnace at the Sundown mine near Stanthorpe, operating on arsenical tin ore, has a flue 200 feet long, admittedly too short, with 12 chambers each 10 feet long and about 6 feet in section, while an Edward's furnace at Jibbinbar has a flue 600 feet long and goes direct to the stack. The latter has five long chambers or subsidiary flues set off at right angles to the main flue, through each of which the fumes pass forward on one side and then backward on the other, with a bratticing as a central screen. In some foreign works the flues are said to be over a mile in length. In section the condensing flues are usually about 6 or 7 feet square, and usually with baffles of bagging or other material placed about 5 feet apart and attached alternately to opposite walls at right angles, with an opening about 2 feet wide.

In an article by E. C. Williams in the *Mining Review*,\* a discussion is given on the merits of certain flues, and as a result of experiments he concludes that "the draft controls impurities, and to a great extent also the density; that deep cooling chambers produce a denser, cleaner and whiter product than shallow ones; that the cooling chamber and furnace should be in a straight line (by which is meant the elimination of all right angle turns) thereby procuring as great a draft as is possible in the furnace

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\* Manufacture of White Arsenic. By E. C. Williams. *Min. Review*, Jan. 5, 1921. Vol. 13, No. 148, pp. 137-9.

with a minimum in the chambers; and that the velocity should decrease the further the fumes travel from the furnace; an effect produced by enlarging each of the cooling chambers as they lead from the furnace."

Operations in Australia show that the arsenical ores treated are generally associated either with gold-bearing minerals, tin-stone, wolfram, or bismuth, and a manager of one of the arsenic works has expressed the opinion, for what it is worth, that arsenic deposits seldom pay to work unless the arsenic is associated with one or more of these minerals. In New South Wales at the Ottery arsenic works at Tent Hill, near Deepwater, a scheme for treating arsenical tin ore is being elaborated and should prove effective, but at present the coarse ore is being roasted in five kilns, and the fines in a rotary furnace, the fumes from both being conducted together into one of two sets of 33 chambers, each set being used alternately. Subsequently the crude arsenic obtained by this means will be treated in a reverberatory furnace and the refined product then finely ground in a burr-stone mill.

In Victoria the small quantities of complex sulphide ores produced there, on which the arsenic works principally depend, are frequently auriferous, and in the roasting operations, which are carried on in mechanical reverberatories, they become valuable by-products. Many years ago the arsenic was considered a nuisance, and on account of the carelessness of those producing it regulations were made to compel the product being destroyed or else buried in some of the old abandoned mine workings.

At Stannary Hills in the Herberton District a Merton reverberatory furnace is operating on an arsenical ore at the Lass o' Gowrie tin mine. Details of the operations are not available, but it is proposed to instal a complete arsenic-saving plant. At the Jibbinbar State Works the Edwards reverberatory furnace in operation has a nominal capacity of 25 tons a day of 24 hours. The ore is treated as it comes direct from the mine without concentration, but is crushed to pass through a screen of  $\frac{1}{8}$ -inch mesh. As the ore enters the furnace it contains an average percentage of 9.58 of metallic arsenic (12.38 per cent. of arsenious oxide), and in the residue there is 0.51 of metallic arsenic (0.67 per cent. of arsenious oxide), but what the actual recovery is one is unable to say. The residue is considered to be of no value either for any metal it may contain or to make pigment, and so is discarded. The flue product without retreatment contains an average of over 90 per cent. of arsenious oxide, and in this impure form it is marketed. No doubt there is a loss of arsenic in the treatment, both in the residues and in the flue

gases, but the former might be allowed to contain a small percentage of arsenic, as the elimination of the last traces requires an abnormal quantity of fuel and would not be economical to remove, while on the other hand there would probably be some advantage in having additional appliances to save all that is possible from the flue gases, the cost of which in the long run would be compensated for by a higher recovery.

At Sundown near Stanthorpe the mineral operated upon at the local works is arsenical tin ore, which is first crushed and concentrated. This concentrate, containing tin ore and arsenical pyrites, is then roasted in a Merton furnace to drive off arsenic and sulphur which mix with the fuel gases, the residue consisting of tin oxide, silica, and iron oxides. This residue is then reconcentrated, the slimes from the machine being made up of silica and iron oxides, and the concentrate of pure tin oxide. The flue dust contains silica, iron oxide, carbon, and 33 per cent. of arsenious oxide, and in this very impure condition is sold to refiners or otherwise disposed of. The capacity of the plant is from 8 to 10 tons of ore per twenty-four hours.

The crude arsenious oxide or "arsenic soot" collected in the flues is usually of a grey colour with about 10 to 25 per cent. of impurities, and in this refined form has many industrial uses. When made direct from ore in furnaces heated with coke, gas, oil or heated air, the arsenic has a low ash contents, and is white in colour, and does not require any further treatment for most purposes. If refining becomes necessary, however, the same furnace and flues may be used, although a small reverberatory—sometimes a muffle—with separate chambers and flues is generally added to a works for this special purpose. In the refining operations arsenical "glass" or "slag" is formed in the chamber nearest to the furnace, while a little further away the arsenic is crystallised and sometimes is stalactitic, with a powdery deposit in the more distant and cooler chambers. Usually the crude arsenic has to be refined more than once, occasionally three times, before the standard percentage of arsenious oxide (99.5) is obtained.

The vitreous and crystalline arsenic forms a denser product than the powder (which is desirable), although, if the product has to be in a fine condition before marketing, its reduction by grinding is necessary.

The density of the product is considered an important item in certain localities, as one barrel of the product may be actually

twice the weight of another, although both may contain arsenic of the same degree of fineness. This difference in density is caused by the varying state of aggregation of the product, and special devices have to be employed to minimise the quantity of flour and increase as much as possible the formation of glass or crystal. Experience shows that the further from the furnace the arsenic is carried the more floury and porous it becomes, and a works should be so arranged that the arsenic is condensed and thrown down soon after it is driven out of the heated ore in the furnace.

It would appear from general considerations that the arsenic should be volatilised at as high a temperature as possible with a strong draft, but that once it is drawn away from the furnace some means should be provided for reducing the draft by a gradual enlargement of the chambers. This lessening of the draft would be further accelerated as the distance from the furnace increases, as a reduction in temperature causes the flue gases to contract in cooling and therefore become less in volume.

The question of impurity is also important, and the experiments of Mr. Williams referred to above, leads one to suggest that the draft should be arranged with fine adjustments, and that many devices may be necessary to try before the desired condition is brought about.

In high-temperature distillation it is found that the deposited arsenic frequently has an undesirable reddish discolouration. This is a result of too much heat in the furnaces with an insufficient charge on the hearth, the colour probably being an effect of the fuel gases on the oxide. When this defect occurs the discoloured product is simply put back for redistillation.

*Red and Yellow Arsenic Glass.*—In the manufacture of realgar or “red arsenic glass” by the subliming of mispickel with iron pyrites, or of mispickel with crude sulphur, equal weights of the former two minerals, or a less proportion of sulphur, are heated in a furnace built up of rows of iron or fireclay retorts each about four feet long and six inches in diameter, the retort pipes leading into sheet iron boxes which act as condensers. In practice it is found that experimental work is necessary in determining the respective quantities to use in the retort to obtain the colour required, and that in the residues a small percentage of arsenic and a large percentage of sulphur is generally present. A charge would amount to about 60 pounds, which is heated to redness for about ten hours.

The condensed product is made up partly of glass and partly of powder, the former being ready for refining, the latter being returned to the retort with another charge. In *retorting* the object is to make a product having an excess of arsenic, but in *refining* usually sulphur is added to obtain the red colour desired. The operation is performed over a bright fire in cast iron pots about two feet in diameter and depth, the charge being stirred with an iron bar for about two hours. The slag and other refuse from these operations are put into the white arsenic furnace, and the finished product, taken from the iron moulds into which it is poured, and containing one part of sulphur to three of arsenic, is ground to a fine powder and packed in barrels.

In making "yellow arsenic glass" the two ingredients used are arsenious oxide and sulphur, the proportions being determined experimentally according to the tone of colour required. From four to ten per cent. of sulphur is generally used with the oxide and this gives a product varying from three to six per cent. of sulphide of arsenic with traces of free sulphur, the rest of the glass being arsenious oxide. The process is operated in the retorts used in making red glass, and similarly the fused portion of the product is that refined, the powdery or streaky portion being returned to the retorts, and the slag sent to the roasting furnace.

*Electrothermal Arsenic.*—Mispickel and other arsenical ores are treated in an electric furnace with an alternating current and cast iron electrodes, and a process known as Westman's is now being applied on a practical working scale in Canada.\* The furnace and condenser are connected with one another and sealed, and the volatilised arsenic in the furnace is received into the condenser without oxidisation. The oxygen in the air contained in the closed system is removed by the first portion of the arsenic volatilised to make arsenious oxide, after which no further oxidisation takes place and the distillate is pure metallic or "elemental" arsenic. A blower is required to send the arsenic fume into the cooling chamber or condenser, and as the arsenic is thrown down the current of nitrogen (air without oxygen) is returned again to the furnace for another charge, the operation being continuous.

The furnace has a capacity of about 200 pounds of ore per hour, and treats mispickel or other arsenical minerals. The temperature is not very high and the iron and sulphur remaining in the residue forms a sulphide of iron in which such metals

\* Electrometallurgy. Electrolytic and Electrothermal. By E. K. Rideal (Bailliere), London. 1918. 247 pp.

as gold, silver, and copper collect, and which have to be removed by other well-known processes. A ton is said to require 1,000 kw. hours for treatment.

The ordinary metallurgical production of metallic arsenic is referred to on page 299.

### Uses of Arsenic Compounds.

(See further references *under* Metallurgical and Chemical Notes).

*Pigments.*—Scheele's Green is an arsenite of copper; Paris Green, Emerald Green, and Mineral Green are aceto-arsenites of copper; Orpiment or King's Yellow is a sulphur-coloured arsenious oxide; Realgar is a red sulphide of arsenic. Lighter tones of all these colours are produced by mixing with barytes, but with orpiment the barytes may be chemically combined to produce a sulph-arsenite of barium, a very fine yellow pigment, the tone of which can be modified by the addition of barium chloride in the process of manufacture. For use in interior decorations these greens and yellow pigments are by no means desirable, as the condition in which the arsenic occurs makes the paint very poisonous. For outside decoration the greens are used to some extent because they form decidedly attractive colours. As an anti-fouling paint arsenic compounds have been used experimentally for ships' bottoms, but with what result is not known. In colouring paper some of the arsenical compounds were once used extensively, but they are now discarded.

*Dyes.*—The ammoniacal solution of orpiment is used as a yellow dye, and the arsenate and arsenite of rose-aniline in solution makes a majenta dye, the latter colour becoming yellow on acidifying with hydrochloric acid. The arsenious oxide is also used in dyeing, more particularly as a mordant to fix aniline blue. Majenta or fuchsine is a rose-aniline hydrochloride and is the substance used in making "indelible" pencils, the colouring of which is easily removed by treating with dilute hydrochloric acid.

*Fireworks.*—Realgar is variously mixed with charcoal, sulphur, potassium chlorate, barium and strontium nitrates and other colour-producing compounds in the manufacture of blue green, red and purple fire.

*Preservatives.*—White arsenic is a preservative for fur and other skins, the compound containing it usually being made up of soap, white arsenic, lime, and camphor. Sheepskins, hides, &c., when put into bales are generally treated with a solution made up of 3 lb. of arsenite of soda and 4 gallons of water, a wash of

this preserving them from the attacks of weevils, &c. As a preservative for wood a solution of white arsenic and caustic soda is placed in holes bored for the purpose, the general absorption of the arsenic solution taking place along the fibres of the wood. A solution of one part arsenic to thirty of water (cold) or ten of water (hot) is also considered to be good. The preservation of dead bodies for post-mortem examination or for removal to distant places is sometimes effected by an injection of a solution of white arsenic into the veins and stomach, decomposition being prevented or delayed by this means, but a stipulation is made under the Government Poisons Regulations (see page 331) that no undertaker shall use arsenic for the purpose of embalming any dead human body. The bodies of those who have died from chronic arsenic disease, a result of eating arsenic in excess or working for a long time in contact with it, do not decay for a long time, the arsenic acting as an embalming reagent.

“Rough on Rats” and similar mixtures which contain arsenic as the poisoning ingredient, usually consist of white arsenic, barium chloride, flour, and a conspicuous colouring ingredient, the arsenic partly destroying the unpleasant odour which otherwise results from the decay of the bodies and thus acting as a preservative as well as a poison. Arsenic is used at times in the holds of ships, the powder being sprinkled on the bottoms to prevent, to some extent, the decay of the vegetable refuse which accumulates from cargoes.

*Medicine.*—White arsenic has several applications in medicine, and the eating of white arsenic as a tonic is a common practice in some countries. Mountain climbers are said to take it to produce greater stamina for their work, and children who are to be employees in arsenic works are taught to eat it in large doses that they may become immune to its poisonous effects. When the arsenic eating is discontinued after constant use, the tissues change and produce metabolism, so that once the eating of it becomes a habit the system demands its continuation. Habitual arsenic eaters take several grains of white arsenic without feeling any ill effects, but normally a fatal dose consists of about two grains.

Arsenic has a caustic effect on the skin and unless care is exercised sores develop on parts of the body made wet by perspiration. The men employed at arsenic works have to be protected with special clothing and fume helmets and even then sores appear on the skin where they perspire. It is said that the men about the furnaces are not allowed to work sufficiently hard “to raise a sweat,” and it is also stated, for what it is worth, that men with fair skins are much more subject to sores than

those with dark ones. In some works and mines the face and other portions of the body are covered with a paint made of freshly prepared hydrous oxide of iron, while thoroughly washing after working is very necessary.

Arsenate of Potash (Fowler's Solution) is taken for some intermittent fevers and is said to be efficacious in certain nervous afflictions. A solution of arsenious oxide in hydrochloric acid is in India used as a cure for hydrophobia and snake bite. Salvarsen (606) an arsenobenzol containing 34 per cent. of arsenic, is used for certain diseases in the form of emulsions and also as solutions for injection, Neo-salvarsen (914) and Hectine being somewhat similar compounds. Many other organic combinations with arsenic, also the arsenate of copper, arsenate of iron, arsenite of iron, and arsenate of soda have medicinal applications.

In veterinary work arsenious oxide is used as a drug for horses, improving their condition and giving to their coats a fine glossy appearance. It is said, however, that after being taken for two or three months the use of the drug must be discontinued for a much longer period, the accumulated arsenic otherwise seriously injuring the system. For ulcers white arsenic is said to be a remedy when applied as a caustic.

In South Africa a fatal disease known as "white scour" attacks calves, and arsenate of soda is used as a remedy. It was observed that the animals recovered after licking their coats subsequent to being dipped, and this led to the use of the compound for this purpose.

Arsenite of soda mixed with bluestone (sulphate of copper) is a recognised vermicide for "wire worms" in sheep. The medicament is made up of one part of arsenite and four parts of bluestone, and given either dry or with acidulated water. Another specific containing 2 oz. of white arsenic, 6 lb. of Epsom Salts, and 5 gallons of water is considered the best drench. It is prepared by boiling the ingredients with half the water for an hour then adding the other portion. The dose is from one to two ounces of this solution according to age. A good drench is made up of 1 oz. of white arsenic, 2 oz. of soda,  $\frac{1}{2}$  lb. of Epsom Salts and 3 gallons of water, prepared as above and administered in the same quantities.\*

*Glass and Enamel Making.*—Arsenious oxide is used for the purpose of producing opacity, translucency and clearness. When glass-making ingredients contain certain impurities which

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\* W. S. Brown in "Farmer's Sheep." See Bibliography.

have to be removed, the oxides of arsenic or antimony form part of the charge, while other impurities require manganese dioxide, or nickel oxide, all of which produce clearness if added in small quantities.

Translucency, opalescence, and opacity are produced either by excess of arsenic or by bone ash, fluorspar, oxide of antimony, or sulphide of antimony, but excess of manganese or nickel makes the glass either purple, brown, or black according to treatment. White bath enamels are frequently made up with arsenic, but in cooking utensils other non-poisonous ingredients are used.

An opinion has been expressed by a representative of an arsenic distributing firm that most of the white arsenic consumed in the Commonwealth is used in glass-making. While this might be true, the consumption in the manufacture of insecticides, such as dips, sprays and powders, is also very large, and the application of arsenic for such purposes is rapidly increasing.

*Arsenical Cigarettes.*—These are made in the ordinary way with tobacco but the paper is impregnated with arsenate of soda, each cigarette containing three-quarters of a grain of this compound. To make the smoking of these cigarettes effective, it is necessary that the fumes be deeply inhaled.

*Dentists' Paste and Fibre.*—Arsenious oxide mixed with morphine sulphate (or cocaine) and enough creosote to make a stiff paste is used on cotton wool to destroy the nerves in hollow teeth as a preliminary to stopping, and a fibre made by mixing tannin, arsenious oxide, and morphine sulphate into a paste with creosote or carbolic acid and then with cotton wool is used for the same purpose. It has been pointed out by medical men, however, that the use of arsenic preparations by dentists should be discontinued.

### **Arsenical Insecticides and Other Arsenical Poisons.\***

*White Ants.*—White arsenic will destroy white ants, and will preserve from destruction the timber which the ants attack. The poison is simply mixed with a little syrup or sugar, or even with sawdust or manure, and placed in their workings. White ants are said to eat one another, so that the termicide may be transmitted from one to the other.

Arsenite of soda is also a common white ant poison and is prepared in the usual way as described on page 301. Arsenic with oil is also used, and for this purpose, washing soda and white arsenic is mixed with a wood-preserving oil (one lb. of

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\*Compiled from notes kindly supplied by H. Tryon, Government Entomologist.

arsenic to 4 gallons of oil). This will protect the wood and kill the ants. The oil is probably "sulphonated," reference to which is made on page 305.

White Ants in fruit trees are destroyed by placing a mixture of sawdust and white arsenic just beneath the soil around the trunks of the trees. Another mixture used in the same way is 3 lb. of bran, chaff, &c., mixed with  $\frac{1}{2}$  lb. of molasses,  $\frac{1}{2}$  oz. of arsenite of soda, and moistened with water (Transvaal remedy).

Arsenic and sulphur is made into a mixture in the proportion of 11 to 3, respectively, and burnt on charcoal in a small vessel made specially for the purpose. The fumes as they come off are blown or pumped into the white ants nests, and the results are said to be very satisfactory.

*House Ants.*—Arsenite of soda with tartaric acid has been used effectively as a poison for some of the house ants. Two lb. of sugar,  $\frac{1}{2}$  dram of tartaric acid, and one pint of water are boiled together, then mixed with  $1\frac{1}{2}$  drams of arsenite of soda. This solution is placed in a small vessel with a piece of sponge or any other porous material which will absorb it. A white arsenic solution in water, of about  $\frac{1}{4}$  per cent. strength, with a little sugar or syrup, and placed in a vessel as above is also a good remedy.

Arsenic and sulphur is used for killing house ants in the manner described under White Ants.

*Grubs.*—White arsenic and arsenate of lead are used in destroying sugar-cane beetles by mixing with manure and then distributing over the soils containing the caterpillars. Successful experiments show that 80 lb. of white arsenic should be used for one acre of soil.

*House Flies.*—Arsenite of soda is good for the destruction of house flies. A Transvaal specific is made up of 5 lb. of this compound with 5 to 20 lb. of sugar and 25 gallons of water, the fluid being sprinkled on pieces of sacking or other material suspended about the rooms. It must be noted, however, that the quantity of poison given in this specific is in excess of what is actually required when mixed with the other constituents.

Another house fly specific is made up of 1 lb. of arsenite of soda and 12 lb. of glycerine (or 5 lb. of sugar with water). Cotton wicks or other absorbent fabrics are placed in shallow tins and kept moistened with the mixture. Arsenate of potash dissolved in water is also good if used in the same way.

*Fruit Flies.*—Mally's mixture is made up of 1 lb. of arsenate of potash, 7 or 8 lb. of molasses, and 25 gallons of water.

Shallow tins are filled with it, from which absorbent wicks are kept saturated. The olive fly in Italy is poisoned by spraying the olive tree with a mixture of 2 parts of arsenate of potash, 40 parts of molasses, and 18 parts of water.

*Sheep Blowfly*.—Arsenite of soda is being employed in Queensland for this purpose. What is known as Cooper's dip (a soda-sulphur-arsenic preparation) is made up with water and jetted into the breach of the sheep with a special appliance. A committee dealing with the matter in this State suggests using 10 lb. of this special dip, with 30 lb. of arsenite of soda (made of 4 lb. of white arsenic, 8 lb. of washing soda, and 5 gallons of water), one gallon of which at a pressure of 100 lb. is sufficient to jet six sheep.

*Grasshoppers*.—White arsenic, arsenite of soda, arsenate of lime, and Paris green are used for the purpose of killing locusts, and are individually applied to both pasturage and crop plants if the destruction of such is of no serious consideration. These poisons are also used with fodder, sugar-cane, bran, manure, sawdust, &c., and sometimes mixed with ingredients specially attractive to grasshoppers, such as molasses, salt, bananas, apples, and lemons, and even with lemon extract.

White arsenic and bran forms a simple locust poison, 1 lb. of the arsenic being mixed with 5 lb. of the bran. A recent Californian formula is 1 lb. of white arsenic, 5 lb. of fruit pulp or lemon, 25 lb. of bran, and 4 gallons of water. The usual practice is to use arsenite of soda and not white arsenic in such mixtures.

Paris green was formerly employed for killing locusts, but recently has been supplanted by other arsenical compounds. It is employed as a spray mixture made up of 1 lb. of Paris green, 1 lb. of powdered lime (which neutralises any free arsenious acid present), and about 50 gallons of water. Canadian practice is to mix moistened bran or sawdust with either salt or sugar, and to blend 20 lb. of this with 7 lb. of Paris green.

Arsenite of soda is generally employed when the locusts occur in swarms, its solubility causing speedy mortality.

Arsenious sulphide is a compound only slightly soluble in water, but being soluble in the gastric juice of the locust it would appear to be suitable as a poison. Nevertheless, it cannot be used as it readily decomposes into arsenious oxide and free sulphur on exposure to sunlight.

*Ticks*.—A very important use of arsenic arises from its efficacy in destroying the various kinds of ticks occurring on

cattle. Such ticks produce “tick worry” and also transfer from one animal to another the blood parasites causing “redwater,” and for the purpose of their destruction arsenite of soda is principally used, although other arsenical compounds are also available to a limited extent.

In tick destruction arsenical compounds do not act as a contact poison, neither do the ticks die as a result of the poison being absorbed through their skin, or from eating it. The arsenic is actually absorbed by the skin of the cattle, and remains for a while in the fluid near the surface of the skin, and this fluid the ticks imbibe.

Arsenite of soda is the arsenical compound almost exclusively used in Australia, South Africa, and America for tick extermination, and is applied either as a spray or dip. It cannot be used simply as an aqueous solution on account of its caustic action on the skin, but combined with certain other compounds called “medicaments” answers all requirements.

Medicaments A and B, the use of which is officially recommended in Queensland, are as follows:—

QUEENSLAND MEDICAMENTS.

A.	B.
White arsenic .. .. 8lb.	White arsenic .. .. 8lb.
Caustic soda .. .. 4lb.	Caustic soda .. .. 4lb.
Stockholm tar .. .. ½ gallon	Bore oil .. .. 1 gallon
Tallow, or oil (animal or .. 4lb. vegetable)	Water .. .. 400 gallons
Water .. .. 400 gallons	

Details of method of preparation of each (A and B) are given on leaflet of instructions issued by Queensland Agricultural Department, entitled “Dipping Medicaments and Directions for their Preparation and Analyses.” (*See Bibliography.*) Commercially prepared dip concentrates may be substituted for the above under certain conditions mentioned in this official leaflet, and an official list of the dips fulfilling these conditions is issued periodically.

Dipping fluids must be analysed at stated intervals and all owners of dips are required to forward samples for this purpose.

The New South Wales official dip contains 8 lb. of white arsenic, 12 lb. of washing soda, 2 lb. of common hard soap, one gallon of best Stockholm tar, and 400 gallons of water.

Arsenate of soda is far less efficacious than arsenite of soda as a destroyer of ticks, and experiments have shown that the arsenate possesses 40 to 50 per cent. less tick-killing power than the arsenite (Cooper and Laws). Analyses have also shown that dipping fluids in use become impaired through the oxidation of arsenite to arsenate (Brunnich) and it has been shown that while some organisms produce this change there are other organisms which will change the arsenate to arsenite.

A special committee appointed under the Bureau of Science and Industry is investigating the effect of arsenic as a parasiticide, and has in view some research on the strength of dips according to the time of year in which they are used and the climatic conditions where they are used.

*Poisoning Rodents (Rats, Rabbits, &c.).*—White arsenic is used as one of the poisons for rats and rabbits, 1/20th grain being the amount of a fatal dose in the latter case. As a powder, it is mixed with any attractive food, or  $\frac{1}{2}$  lb. of the poison is mixed with 2 gallons of water, reduced to one gallon by boiling, to which is then added 2 lb. of sugar. This mixture is stirred into bran, crushed carrots, &c., 25 pounds of which is about the quantity required to absorb it, bran being preferred to oats or wheat. The material so prepared is placed in small heaps or furrows or in convenient receptacles in the vicinity of the burrows or holes. Herbage on which rabbits feed is sprinkled with the arsenic solution, and drinking water may also be poisoned. One gallon of water boiled for an hour will dissolve  $\frac{1}{4}$  lb. of arsenic and this solution is added to the water. Certain precautions, however, have to be taken when arsenic is used for such a purpose, otherwise there is the danger of stock being destroyed. Rat poison made of arsenic is better placed near water because the arsenic creates thirst, and quenching the thirst assists the assimilation of the poison.

*Insecticides injurious to plant and animal life.*—The injury to plants by the use of arsenical insecticides is usually a result of the presence of free arsenious acid (white arsenic), although other arsenical compounds, such as the arsenates of lime and zinc, may also produce injury, for which the remedy is, as previously stated, the addition of lime to convert the soluble arsenic into an insoluble arsenate of lime. Paris green used as a plant spray requires lime added to it, otherwise the foliage is scorched. Peach leaves are particularly liable to this injury, and in a lesser degree also plum and potato leaves. Arsenate of potash and arsenate of lead are both used as tree sprays, but cannot be used on vines because they destroy the pollen of the grape vine flowers.

Insoluble arsenical insecticides are used where the avoidance of injury to the host-plant is an essential feature, and of these the principal are two arsenates of lead, the arsenates of lead and zinc, Paris (or Schweinfurth) green, and arsenic-oil compounds, the compositions of which are given on pages 302-4.

The two lead compounds are the tri-plumbic and di-plumbic arsenates, the latter being the less stable, and therefore the more useful and important. Both are applied either as dust or as liquid sprays, and large quantities are used in this way. These arsenates may be blended with Bordeaux mixture, but not with sulphur-lime compounds, to form insecticide-fungicides. Either as dust or spray they are specially destructive to the codlin moth and also to beetles, weevils, and caterpillars, while mixed with bran and sugar and slightly moistened with water and sprinkled on soils they are very useful in exterminating cut-worms.

Paris green or Schweinfurth green has the same application as the arsenates of lead, but is liable to injure foliage, and therefore an equal weight of lime is necessary to use with it, besides which its percentage of arsenic appears to be somewhat variable. It is applied specially to the destruction of caterpillars, and has been used extensively on the tobacco fields of Sumatra.

Arsenate of lime, including London Purple, references to which are made on page 302, may be used as an insecticide for all the purposes to which the arsenates of lead are applied, especially as a dust spray, although the use of London Purple is almost obsolete. They are the only arsenical insecticides which can be employed with lime-sulphur as insecticide-fungicides.

Arsenate of zinc is used for exterminating cut-worms and leaf-eating beetles and weevils, and when properly prepared as a spray it does not damage the trees, although liable to partial decomposition by exposure to sunlight and therefore liable to injure foliage. It can also be used with Bordeaux mixture, the lime of which neutralises any ill-effects that otherwise might arise.

The use of arsenic-oil compounds is referred to on page 305. It may be noted, generally, that all the above arsenical sprays are prevented from injuring trees and plants by the addition of lime, but they are more effective in insect destruction if a small quantity of caseinate of lime (8 oz. to 100 gallons) is added to the mixture.

Possible objections to the use of these arsenates are discussed below under the heading of soils, bees, fruit, tobacco, and wine.

Soil.—The destruction of weeds through the medium of the soil has already been commented upon. With apple trees a canker results if the applications of the poison spray on the soil about the base are too numerous—although the data on this point are not conclusive. No doubt, however, the presence of arsenic stimulates the ammonifying and nitrifying organisms concerned in producing soil fertility, and it appears that even large quantities of arsenic can be chemically absorbed by the soil before the toxic effect on these organisms becomes marked.

Bees.—Sprays on fruit trees in bloom are said to be destructive to bees, but that this is so wants confirmation.

Fruit.—The fruit on apple trees was thought to be affected by spraying with arsenical solutions, but it has been shown that any residue on the fruit when harvested is quite harmless, and that the spraying does not injure it as an article of food.

Tobacco.—The remarks on fruit injury apply equally to tobacco. Small quantities of arsenic have been detected in the manufactured article, but this might be beneficial rather than injurious.

Wine.—French vignerons give vines as many as six sprayings with arsenate of lead. It has been observed, however, that while ordinary and sour wines made from the fruit contain no arsenic, residues from the wine contain the poison and may be dangerous.

*Arsenic mixed with Fungicides.*—Both fungus diseases and injurious insects ordinarily require distinct specifics, but if both occur on the same plant, an insecticide can be combined with a fungicide without impairing the virtue of either, and thereby lessen the cost of spraying. With Bordeaux mixture, which is a fungicide, all the principal arsenical insecticides can be incorporated, but the proportions depend on their respective killing powers. It is customary to add the arsenical solution to the slacked lime used in making the Bordeaux mixture.

In sulphide fungicides (sodium sulphide, lime-sulphur, &c.) only arsenate of lime can be safely used, as decomposition takes place with other arsenical compounds, and even then freshly slacked lime must be added.

Either arsenate of lime or arsenate of lead, it may be noted, can be effectively combined in the same spray fluid with nicotine sulphate (40 per cent.) if used as a contact insecticide-fungicide, and both these arsenical compounds would be available for distinct classes of insects.

*Prickly Pear Destruction.*—The principal illustration of the use of arsenic in this respect is afforded by its general employment in one form or another in Australia and other parts of the world, and the bibliographical references given in the Report of the Prickly Pear Commission\* will serve to indicate its importance as a noxious weed destroyer. The Annual Reports of the Prickly Pear Experiment Station at Dulacca† afford further information on the subject. The experiments were conducted by Dr. Jean White (Mrs. J. W. Haney) under the auspices of the Board of Advice on Prickly Pear Destruction, and embody much original research, dealing largely with arsenic as a cacticide in the form of powders, liquids, and vapours.

Further, the Cactus Estates Limited exploited on an extensive scale a special arsenic combination in the form of arsenious chloride, reference to the composition of which is made under “Chemical and Metallurgical Notes,” on page 301.

Arsenite of soda is also a powerful prickly-pear destroyer. It is used either as a powder or as a liquid, a special injector being used in the former case. As a powder it is prepared by combining 15 lb. of common salt with 10 lb. of white arsenic and 4 lb. of caustic soda (Brunnich Arsenic Mixture), while as a liquid injection this powder is mixed with 8 gallons of water. For spraying purposes the powder is mixed with 100 gallons of water, the pear being slashed and cut down prior to applying the spray.

Arsenic acid uses in prickly-pear destruction was a special feature in the investigations of Dr. White some time ago, who was probably the first to use it for this purpose. The mode of employment under experimental conditions is fully detailed in the 1915-16 volume of the Annual Reports referred to above, reference also being made therein to the cost of manufacture, which at that time was 3½d. per lb. for commercial arsenic acid and 5½d. per lb. for 98 per cent. arsenic acid. It is claimed that this chemical is superior to all other specifics for pear destruction, and there is undoubtedly a great demand for it at the present time. It is stated that half an ounce of a 20 per cent. solution will destroy 1 cwt. of prickly-pear, and as a spray half a gallon of a 2.5 per cent. solution will produce the same effect, but for using with an “atomizer” a much stronger solution should be employed (Dr. Jean White).

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\* Report of the Prickly Pear Travelling Commission. See Bibliography.

† Annual Reports (4) of the Prickly Pear Experimental Station, Dulacca. See Bibliography.

Recently there has been put on the market a mixture of arsenic and sulphuric acids which, as previously stated, has shown good results.

Arsenious chloride is applied to prickly-pear destruction by means of an atomizer without being diluted in any way, its vapour in spreading over the ground producing rapid contact with the pear. Owing to its volatility its use is difficult to control, and by reason of its rapid potency as a poison, it attacks the surface tissues of the pear exclusively, and to some extent is a drawback to its use.

Arsenic trihydride or arseniuretted hydrogen (arsine) applied as a vapour for pear destruction at Dulacca has been tested, but its use did not proceed beyond the experimental stage.

It may be observed that in employing arsenic for destroying pear the time of year when the poison is used and the conditions of the plant itself are factors influencing success.

*Other Weed Destruction.*—Many weeds other than grasses may be destroyed by arsenical spray solutions of certain strength which will not injure the grasses associated with them; either neutral or acid arsenite of soda being the compound mostly employed.

In common practice this poison is made up of a strong solution containing 5 lb. of white arsenic, 5 lb. of carbonate of soda, and 10 gallons of water, the solution and union being effected by boiling for about an hour, this being added to 100 gallons of water when required for spraying.

It is used in destroying weeds in cultivated lands, and in some countries along railways and roads. It is also applied to the surface of tennis courts, paths, &c., and prevents all weed growth if sprayed at intervals. The same mixture has been used at Panama extensively for the destruction of the Water Hyacinth.

Arsenious chloride can also be used as a weed destroyer, but it has to be used in the form of a vapour and requires for its application a special apparatus, so that certain disadvantages are associated with its use.

*Note re Arsenic and Soil Fertility.*—In the destruction of weeds several applications of the poison may be required and therefore the possibility of soil injury has to be considered. In the Hawaiian Islands 5 lb. of arsenic per acre is applied three times per year, but the character of the soil must be understood and indiscriminate spraying is not advisable. It has also been

observed that soils possess strong fixing powers for arsenic, and that when sodium arsenite is used as a weed destroyer a portion is absorbed by the soil which is not leached out. This result is due to chemical reactions taking place between the sodium arsenite and the other constituents of the soil to produce more stable arsenites and arsenates. (McGeorge, United States Department of Agriculture.)

*Destruction of Living Trees.*—In Queensland and other States much forest country is occupied as grazing areas for cattle or sheep, and to improve it for pasturage purposes the timber on it has to be destroyed. The usual method of killing the trees is by ring-barking, but another method not so common is by poisoning. In the latter case arsenite of soda is used, and the method of operating is to cut into the bark all around the base of the trunk, and into the incision pour a poison solution made up of 1 lb. of white arsenic, 1 lb. of washing soda (or  $\frac{1}{2}$  lb. of caustic soda),  $\frac{1}{2}$  lb. of whiting, and 4 gallons of water, the whiting being added that the trees poisoned may be afterwards identified. (Burrows.)

Another method is to fill auger holes bored into the trunk with the poison, which destroys the life of the tree but to some extent preserves the timber from decay. (See under Preservatives.)

In putting into practice the poison method of tree destruction it is necessary to note that the ring-barking must be conducted at a time when the tree is dormant, *i.e.*, when the sap is down, otherwise the results will not be altogether satisfactory.

*Preservatives for Wood, &c.*—Timber may be preserved from insect attacks by saturating it with a solution of arsenite of soda prepared in one of the usual ways. The Queensland Railway Department's specific for preserving the timber used in wooden bridges and other structures consists of 56 lb. of white arsenic in 45 gallons of water, this being poured into  $\frac{5}{8}$ -inch auger holes bored into the wood for the purpose, after which the holes are plugged. At the end of six months, or sooner, another charge is put into the holes, with other repetitions later on. (R. E. Sexton, Queensland Railways.) (See also page 313.)

A common practice throughout Queensland is to preserve the "stumps" or supports for wooden buildings by a solution of arsenic, the operation also making the timber immune from the attacks of white ants. Preservatives of this nature aim principally at preventing the destruction of timber by these termites,

but the injuries of other timber-destroying insects such as “powder post” beetles (*Anobium spp.*) may also be frustrated by their adoption.

*Wood Pulp Products.*—In preserving from the attacks of insects the wood fibre or composition boards now used in building construction (as a substitute for wood laths and for internal finish) experiments in the United States have been made with potassium dihydrogen arsenate and other arsenical chemicals, but a large quantity of water is used in the wood-pulping process and it is found that very little of the arsenic is retained. The cost of effective treatment is high, so the process cannot be said to be at present commercially successful. (T. H. Snyder.)

### Production and Values.

The United Kingdom has the largest total production of arsenic in the world, the quantity of white arsenic alone amounting to 220,065 tons to the end of 1917, the value being £2,126,005, or at the rate of £9 13s. 3d. per ton. In addition the amount of arsenical ore produced in England up to 1915 totalled 193,054 tons, having an average value of 13s. 4d. per ton.

Germany, up to 1902, produced white arsenic to the value of £1,013,308, with an average of £15 17s. 6d. per ton. Recent returns are not available. The United States production of white arsenic reached a value of £1,184,564 up to 1919, with £25 0s. 8d. per ton as the average value, the Canadian yield being valued at £591,564 up to 1919, with an average value of £24 17s. 9d. per ton. Portugal's small production averaged £10 9s. 4d. per ton, while Spain and Italy's productions realised a little over £17 per ton, with Japan's at about £15 per ton.

The lowest average value for white arsenic is that produced in the United Kingdom, the returns extending over a large number of years when the value of arsenic was very low, while the highest, so far as records show, is that of Queensland, whose small production averaged £41 8s. 2d. per ton.

In Table 88 is given the production of the countries producing arsenious oxide and arsenical ores. The figures are fragmentary, although sufficient to show the position of the United Kingdom and Germany in the past as the principal sources of the arsenic supply of the world. The values attached to the production given in the table show considerable variation, and in the case of arsenical ores include the values of whatever they might contain in the way of other metals.

*Preservation of hides, skins, &c.*—Reference is made to this on page 312.

The statistics showing annual yields of most of the countries are given in Table 89, but there are no returns of the recent productions of Germany, Spain, Portugal, Japan, France, and Italy, so that the information is very incomplete. Nevertheless, from the data supplied in the Table the total production of arsenic in the United States is shown to be more than double that of the United Kingdom, and is about equal to the combined productions of the United Kingdom and Canada. Germany's production must be a very large one, and from Japan's activity it is evident that arsenic is being produced in that country, or in areas in some of the eastern countries with which she is in touch.

Within the Commonwealth no figures are published concerning arsenic yields except those of Queensland, although Victoria is said to be producing several hundred tons of white arsenic annually. The Queensland yield for 1920 is 250 tons of white arsenic, which represents eleven months' production from 2,938 tons of mispickel-bearing quartz, the 1921 production for the first four months being 117 tons of white arsenic from 1,294 tons of ore. The annual consumption of white arsenic within the Commonwealth is estimated to have been 1,000 tons for some years past, but with the increasing demand for prickly-pear poison this amount is now much exceeded, and in the near future Queensland alone will be using this quantity.

Exports of arsenic are recorded from the United Kingdom and Canada, and are given in Table 90. The wide difference between the exports and productions of the United Kingdom shows that a large consumption of the commodity takes place locally, while with Canada the small difference between the production and export figures indicates that nearly the whole of the output goes to other countries as white arsenic, to be there manufactured into arsenical preparations. During the course of the war the demand for arsenic was so great for munition purposes that all the supplies available in Australia were shipped to England, although in the Commonwealth Statistics this is not shown, but placed under, it is assumed, "drugs and chemicals."

Import figures for the United States and Canada are given in Table 91, and indicate that the former country some years back imported more of her arsenic requirements than what she produced, but that during recent years her imports and productions were about equal. Canada, which exports so much, also imported some of the article, but the quantities were merely nominal.

TABLE 88.—TOTAL PRODUCTION OF ARSENIC BY COUNTRIES.  
(Compiled from various sources.)

Country Producing.	Year of Production.	Products.	Produc- tion.	Value of Production.	Value per ton.
			Tons.	£	£
United King- dom	1860-1917	White arsenic	220,056	*2,126,005	9 13 3
	1875-1915	Arsenical ore ..	193,054	*128,249	0 13 4
United States	1901-1919	White arsenic	47,319	1,184,564	25 0 8
Canada ..	1885-1919	White arsenic	23,762	591,565	24 17 9
	1907-1919	Arsenical ore ..	3,840	23,537	6 2 7
Germany ¶ ..	1852-1902	White arsenic	†63,829	1,013,308	15 17 6
	1903-1911	Arsenic salts ..	25,459	..	..
	1852-1912	Arsenical ore ..	164,294	544,354	3 6 3
France ..	1898-1913	Arsenical ore ..	229,873	* 262,913	1 2 11
Japan ..	1881-1915	‡ White arsenic	423	6,355	15 0 0
Spain ¶ ..	1879-1903	§ White arsenic	3,430	60,590	17 3 3
	1904-1911	§ White arsenic	8,219	..	..
	1892-1911	Arsenical ore ..	40,740	21,117	0 10 4
Italy ¶ ..	1895-1900	White arsenic	1,239	21,933	17 10 0
	1901-1911	White arsenic	659	..	..
	1897-1910	Arsenical ore ..	719	2,115	2 18 10
Austria ¶ ..	1873-1880	White arsenic	327	2,250	6 17 7
	1869-1908	Arsenical ore ..	2,083	1,843	0 17 8
China ¶ ..	1907-1912	White arsenic	1,979	..	..
	1907-1912	Orpiment ..	1,897	3,294	1 14 8
Portugal ..	1897-1914	White arsenic	18,615	* 194,853	10 9 4
Queensland ..	1917-1919	White arsenic	156	6,460	41 8 2

\* Estimated in part.

† Includes sulphide.

‡ Includes "metallic" arsenic.

§ Includes other compounds.

|| Figures for 1911-1916 not available.

¶ Figures for recent years not available.

TABLE 89.—ANNUAL PRODUCTION OF ARSENIC BY COUNTRIES (1914-1919).  
(Compiled from various sources.) Incomplete.

Country Producing and Product.	Years of Production.					
	1914.	1915.	1916.	1917.	1918.	1919.
United Kingdom—						
White arsenic Tons	1,988	2,496	2,534	2,574	2,226	2,451
Value £	19,052	*32,450	*53,200	*142,000	*122,400	*135,000
Value per ton £	9 11 8	13 0 0	21 0 0	55 0 0	55 0 0	55 0 0
Arsenical ore Tons	..	421	300	378	..	..
Value £	..	*400	*300	*350	..	..
Value per ton £	..	0 19 0	1 0 0	0 18 6	..	..
United States—						
White arsenic Tons	4,170	4,909	5,345	5,492	5,645	5,383
Value £	65,232	63,941	115,664	232,982	252,708	240,959
Value per ton £	15 12 11	13 0 6	21 12 9	42 8 5	46 10 10	44 15 3
Canada—						
White arsenic Tons	1,550	2,139	1,951	2,371	2,216	2,377
Value £	21,670	30,797	54,656	137,131	108,443	101,619
Value per ton £	13 9 6	14 8 0	28 0 3	57 16 9	48 18 9	42 15 0
Arsenical ore Tons	..	..	..	250	962	473
Value £	..	..	..	2,333	8,982	4,375
Value per ton £	..	..	..	9 6 8	9 6 9	9 5 0
Queensland—						
White arsenic Tons	..	..	..	32	66	58
Value £	..	..	..	580	2,980	2,900
Value per ton £	..	..	..	18 2 5	45 3 0	50 0 0

\* Estimated.

TABLE 90.—ANNUAL EXPORTS OF ARSENIC BY COUNTRIES (1914-1918).  
(Incomplete.)

Country Exporting and Product.	Years of Production.					
	1914.	1915.	1916.	1917.	1918.	1919.
Canada—						
White arsenic Tons	1,675	2,069	1,763	4,123	2,386	2,218
Value £	27,618	36,289	41,137	108,812	82,059	73,316
Value per ton £	16 15 9	17 10 10	23 6 8	26 7 10	34 7 10	33 1 1
United Kingdom—						
Arsenic * Tons	..	618	722	328	311	904
Value £	..	13,509	29,973	26,781	42,036	72,313
Value per ton £	..	21 17 0	41 16 0	81 13 0	135 13 0	80 0 0

\* Arsenic and its oxides.

TABLE 91.—ANNUAL IMPORTS OF ARSENIC PRODUCTS BY COUNTRIES (1914-1919).

Country Importing and Product.	Years of Production.					
	1914.	1915.	1916.	1917.	1918.	1919.
United States *—						
White arsenic Tons	3,239	2,842	1,931	3,531	5,972	5,839
Value £	57,023	55,578	48,478	140,599	267,044	190,079
Value per ton £	11 12 1	19 11 1	25 2 1	39 16 2	44 17 8	32 11 0
Canada †—						
White arsenic Tons	2½	6	29	211	995 lb.	..
Value £	52	137	1,476	6,684	46	..
Value per ton £	23 12 9	22 16 8	50 18 0	31 4 0	..	..
Arsenical ore Tons	5	77	107	113	135	..
Value £	157	1,128	2,466	4,594	6,948	..
Value per ton £	31 8 0	14 13 0	23 0 11	40 13 4	51 9 4	..

\* Mineral Resources of the U.S.

† Mineral Production of Canada.

### Arsenic Poisoning and Antidotes.

*Poisoning.*—The commonest cases of persons being poisoned by arsenic are those in which the arsenic is taken in a mixture or as a powder, but poisoning also results from inhaling either arsenical fumes or dust charged with arsenical particles, and also by continual contact with the skin, specially if the latter is broken with sores.

The first symptoms are stomach and intestinal pains, then weakness, fainting, vomiting, and convulsions. If the poisoning has been brought on by long contact, such as would result from working at a furnace, there may be the internal pains, thirst, diarrhoea and coughing, although at times without some of these symptoms, and the skin, specially where the perspiration is excessive, may become covered with sores, and more or less shrivelled, while the finger nails may become loose and the hair fall out.

A fatal dose is about two grains if the person previously has not been habitually taking it, and it is more poisonous in the form of a fine powder than if in pieces, and also more pronounced in its effects when the digestive system is acid, and out of order, than when the condition is normal, the stomach acids making it more soluble and easier to assimilate.

*Antidotes.*—(1) Freshly prepared hydrated ferric oxide made into a paste with water and given in tablespoonful doses every few minutes; (2) calcined magnesia (burnt magnesite)

ground into a very fine paste with water and given in large quantities; (3) mucilaginous drinks such as gumwater, olive oil, paraffin oil; (4) stimulants to be used if there is much prostration; (5) application of hot blankets and bottles; (6) a standard formula is made by mixing in a bottle (much larger than is required to hold) three parts of ferric sulphate, or ferric chloride, with seventeen of water, then to mix in another bottle one part of calcined magnesia with nineteen of water. These two solutions should be kept ready for emergency, and when required the magnesian solution is added to the iron one, of which tablespoonful doses should be given every five or ten minutes. The precipitate, which is ferric oxide, may also be collected on a filter made of folded blotting paper, and without washing may be administered in tablespoonful doses.

Vomiting should be induced as a preliminary to using medicines by administering mustard or salt in warm water, if vomiting has not already taken place, the object being to remove as much of the poison as possible before acting on the poison with an antidote.

The first mentioned antidote (1), which is nearly the same as (6), may be made by precipitating the hydrous ferric oxide from a solution of the sulphate by adding ammonia or bi-carbonate of soda. The hydrous oxide should be freshly made, but may be kept in good order for sometime by keeping under water. In addition to using this compound internally it is also good for skin sores produced by arsenic, and is applied as a paste. Burns caused by coming in contact with hot arsenical fumes are best treated with boracic acid. After the antidote has been given and the danger removed a purgative is necessary to remove the ferric oxide from the system, and subsequently large quantities of tea, coffee, or some other such stimulant should be administered.

### Government Poisons Regulations, 1920.

The regulations restricting and regulating the sale and use of arsenic and other poisons in Queensland are issued by the Commissioner of Public Health\* and published in pamphlet form by the Government Printer, Brisbane.

Amongst other listed poisons reference is made to *Arsenic* and its chemical compounds, and medicinal preparations or admixtures containing 0.5 per cent. or more of arsenic calculated

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\* Appearing in *Government Gazette*, No. 177, pp. 1369-1386, April 1st, 1920.

as arsenious oxide ( $\text{As}_2\text{O}_3$ ). The following extracts and notes taken from the Regulations bear specially on arsenic:—

No person other than a registered medical practitioner, pharmaceutical chemist, dentist, or duly qualified veterinary surgeon shall dispense any poison.

No person other than a registered medical practitioner or pharmaceutical chemist shall sell any such poison so dispensed or in packages by retail, unless he is licensed to do so by the Commissioner.

If any person produces to the Commissioner a certificate signed by a registered medical practitioner and a police magistrate that he is a fit and proper person to be allowed to sell any such poison at a place distant not less than four miles by the nearest practicable road from any place in which a pharmaceutical chemist has an open shop, he may, at the absolute discretion of the Commissioner, and on payment of a fee of forty shillings to the Commissioner, be licensed by the Commissioner as a dealer in such poisons.

No person, firm, or company shall sell any poison by wholesale unless such person, firm, or company is licensed to do so by the Commissioner, and no licensed wholesale dealer in poisons shall sell any poison by retail.

The usual fee for a license is 20s., and the license must be renewed before the 30th June.

The poison must be kept in a bottle, vessel, box, or packet, and labelled POISON in red, and placed in a locked cupboard or other receptacle set apart for the purpose, and separate from articles used in the preparation of foods. It must be put in bottles if sold in quantities less than eight ounces and in other approved containers if over that weight, and must be labelled POISON in red.

No person shall sell any poison without first ascertaining from the purchaser his name, place of abode, occupation, and the purpose for which such poison is required. He must also make a faithful entry of these particulars, together with the name of the article and the quantity thereof and the date of the transaction, in a book which shall be kept by the seller for that special purpose, to which the purchaser must sign his name. If the purchaser is unknown a third person must be called in who is known both to the seller and purchaser. This regulation does not apply to the sale of poisons by wholesale dealers to retail traders upon orders in writing in the ordinary course of wholesale dealing.

No person shall sell any arsenic or any uncoloured compound or preparation of the same unless such poison is mixed

before the sale or delivery with soot or some other black substance in the proportion of at least one ounce of soot or some other black substance to one pound of arsenic, provided the arsenic is not required for agricultural or horticultural use.

No undertaker or other person shall use for the embalming of, inject into, or place upon any dead human body any arsenic or compounds, preparations, or admixtures thereof.

The proprietor or manufacturer, if the preparation or article be manufactured in Queensland, otherwise the Queensland importer or agent of any proprietary preparation or article containing a poison shall lodge with the Commissioner a statement giving particulars of the name of the preparation or article, the name of the poison and the quantity or proportion of the same contained therein.

Every police officer in the State of Queensland shall be deemed to be an authorised officer of the Commissioner of Public Health and may take any action regarding the infringement of these regulations.

The provisions of these Regulations, with certain reservations, shall not apply to the sale of any preparation or admixture containing a poison for use as an animal dip or pest exterminator, or packed exclusively for agricultural or horticultural purposes, provided that every such preparation or admixture is contained in a securely closed vessel or in a sealed package, distinctly labelled with the name of the article and the word "Poison" in red letters on a white ground in type larger than that of any other word upon the label, and with the name and address of the seller, and with a notice of the special purpose for which the preparation or admixture is intended. The word "Poison" shall form the first line of the label, and no other word shall appear on the same line; nor shall any other word on the label be written in red letters.

Subject to the following conditions the Commissioner may grant a license to sell any poison for use as an animal dip or pest exterminator or for agricultural or horticultural purposes to any person who is, in his opinion, a fit and proper person to sell such poison:—

The licensee shall pay a fee of twenty shillings and an annual renewal fee of twenty shillings.

(a) The licensee shall keep every article containing such dip or exterminator or poison in such a place and in such a manner as to be separate and apart from goods of any kind suitable for food of man or animals and so as not, in the event of breakage

or leakage, to be likely to intermix with, contaminate, or injuriously affect such goods.

(b) The licensee shall keep a book in which shall be recorded every sale of such poison, the date, the name of the article containing such poison, the quantity of such poison sold, the purpose for which it is intended, and the signature and address of the purchaser.

(c) The licensee shall not sell any such article unless it is contained in an enclosed vessel or receptacle as received from the manufacturer or packer, distinctly labelled with the name of the article and the word "Poison," and with the name and address of the licensee, and the special purpose for which it has been prepared distinctly written thereon.

(d) When any such poison is in a liquid state or is contained in any liquid preparation it shall be sold only in bottles, tins, drums, or casks, of sufficient strength to bear the ordinary risk of transit without leakage.

(e) Each bottle, jar, tin, drum, or cask containing such liquid poison or liquid preparation containing such poison shall have the word "Poison" indelibly printed, marked, or branded thereon in easily legible characters in a conspicuous position apart from the label, and the label also shall bear the word "Poison."

(f) When any such poison or poisonous preparation is sold in bottles or jars the bottles or jars shall be of a distinctive character so as to be readily distinguishable by touch from other bottles or jars employed as containers for any food, drink, or condiment for man or animals.

(g) All articles in the solid, semi-solid, or dry form containing poison for use as an animal dip or pest exterminator or for agricultural or horticultural purposes shall be packed in such a manner as to avoid as far as possible the risk of breakage or leakage during transit.

Every person failing to comply with a notice in writing by the Commissioner under this subclause shall be guilty of an offence against these Regulations.

(h) Every applicant for a license to sell such poisons shall forward with his application for such license a certificate signed by a police magistrate or the police officer in charge of the police station nearest to the residence or place of business of the applicant to the effect that the person making the application is a fit and proper person to be licensed to sell poisons for use as animal dips or pest exterminators or for agricultural or horticultural purposes.

Every person licensed to sell any poison shall affix in a prominent position upon the exterior of his business premises a board or plate upon which shall be clearly stated his name and the words “Licensed Dealer in Poisons,” “Licensed Wholesale Dealer in Poisons,” “Licensed Dealer in Poisons for Agricultural or Horticultural Purposes,” as the case may be.

Every person who sells poisons for any purpose whatsoever shall at all times display in a conspicuous position within his premises the “Poisoning and Treatment” sheet supplied to him by the Commissioner.

The said sheet or sheets shall at all times be maintained by such person in a clean and legible condition.

Attached to the pamphlet containing the Regulations are a number of forms required by dealers, companies, chemists, medical practitioners, and police magistrates, copies of which are obtainable at the Government Printing Office, Brisbane.

### **Government Arsenic-Selling Prices, &c.**

The Government Prices, Conditions, &c., for the sale of crude white arsenic from the State Works at the Jibbinbar Mine, issued on the 1st January, 1921, are as follows:—

(1) Applications (in triplicate) for the supply of arsenic for prickly-pear are to be made, on specially printed forms, to the nearest Mining Registrar or Clerk of Petty Sessions, on which a declaration must be made that the arsenic is to be used exclusively for the destruction of prickly-pear on land owned by the applicant.

(2) Applications for the supply of arsenic for all purposes other than for prickly-pear destruction are to be made, on printed forms, direct to the Mines Department, Brisbane.

(3) Separate applications are necessary when the arsenic is to be used only partially for pear destruction, details of which are to be furnished by the applicant.

(4) The arsenic is supplied in casks and—up to 5 cwt.—in sealed tins, and is forwarded free to any railway station in the State, but all shipping charges are debited to buyers and are collected by forwarding agents on delivery.

(5) The price of arsenic supplied to landowners and local authorities for pear destruction is £10 per ton, the price for all other purposes being £50 per ton.

(6) If packed in casks a charge at the rate of £2 per ton is imposed, and if in sealed tins £3 per ton. Rebates are made if casks are returned to State Works, Jibbinbar (consigned to

Stanthorpe) at the rate of 7s. 6d. per cask, but they must be in good order.

(7) Further details are given in the official "Regulations" issued as a leaflet, and on the official application form.

### Quotations and Market Prices.

In Table 92 are given the average yearly quotations of the principal arsenical compounds, which include arsenate of lead, arsenious oxide, realgar (red arsenic), orpiment (yellow arsenic) and Paris Green (copper arsenic). The prices are exclusively American, but they will probably correspond more or less closely with those prevailing in the United Kingdom. The table is incomplete for the war period, although the prices of arsenious oxide, so much in demand for war purposes, is without a break.

*Arsenious Oxide* (white arsenic) average prices in 1918 were about £110 per ton, although in January of this period the price reached £155 per ton. Commonwealth pre-war prices were somewhat lower than foreign prices, but during the first half of the war they were higher than either English or American quotations. As the war proceeded, however, the English demands and prices were sufficiently high to encourage all Commonwealth producers to ship to England and not to sell locally.\* At the present time (May, 1921) the price for refined white arsenic within the Commonwealth varies about £70 per ton, the standard quality being 99.5 per cent. trioxide.

The prices and conditions for the purchase of Government arsenic are given on page 334 under "Government Arsenic-selling Prices, &c."

*Arsenical Ores* are bought by some of the firms operating arsenic-roasting furnaces and a rough estimate of charges would be £6 10s. per ton of ore containing about 30 per cent. of arsenic, with a penalty of about 5s. per ton per unit below this percentage, and a premium of the same amount if above, with an allowance for gold at the current rate if over 5 dwt. per ton, and no deductions for impurities which would not be deleterious, such as lead, zinc and copper.

*Red and Yellow Arsenic* (realgar and orpiment) prices are not obtainable locally as so little is used in the Commonwealth, but prices in New York (see Table 92) in 1920 were £90 per ton.

*Arsenate of Lead*, for which there is a good demand, and of which there are many makers in the Commonwealth, is sold within the Commonwealth at prices varying above and below £200 per ton. The powders have the maximum prices, while

with pastes and solutions the prices vary according to the proportion of arsenate to the medium in which it is contained.

*Arsenic Acid*.—Roberts's Pear Poison (arsenic and sulphuric acids), for which there is said to be a great demand, is sold at the rate of about £60 per ton. It is put up in jars and steel drums varying from  $\frac{1}{2}$  cwt. up to about 8 cwt.

*Paris Green* prices are generally more than double those of white arsenic, and vary with the price of copper, one of its constituents. Commonwealth prices at the present time are about £220 per ton, this being more than double any pre-war quotation.

*Arsenious Chloride*, which has been used experimentally as a gas in prickly-pear destruction, was in 1917 quoted at about £65 per ton, and in 1918 at about £80 per ton. Recent prices are unknown.

TABLE 92.—ARSENIC QUOTATIONS (1910-1920), NEW YORK.

Year.	Arsenious Oxide* (White Arsenic).	Realgar and Orpiment (Red and Yellow Arsenic (approximate))	Paris Green. (Copper Arsenic).
	£ s. d.	£ s. d.	£ s. d.
1910.. ..	11 19 0	24 0 0	79 6 6
1911.. • ..	10 3 6	20 0 0	18 13 0
1912.. ..	13 8 0	35 0 0	..
1913.. ..	31 10 0	..	..
1914.. ..	17 5 0	..	..
1915.. ..	17 15 6	..	92 0 0
1916.. ..	27 4 6	..	..
1917.. ..	90 0 0	..	..
1918.. ..	110 0 0	..	..
1919.. ..	50 0 0	..	..
1920.. ..	71 0 0	90 0 0	180 0 0

\*" Engineering and Mining Journal."

### Conclusion.

The manufacture of white arsenic in Queensland as a stable industry warrants the suggestion that all the industrial compounds and mixtures made from it should also be produced here. Many of these mixtures, such as cattle and sheep dips, white-ant poison, and sprays for trees and shrubs, are already made in the State, but there is scope for further developments in the making

of important chemicals required in these mixtures, such as arsenic acid, arsenate of soda, arsenite of soda, arsenate of lead, arsenate of lime and aceto-arsenate of copper. This means, practically the establishment of chemical works dealing primarily with arsenical compounds and a staff of technical chemists.

From a general mining point of view the establishment of an arsenic treatment works near railway communication would be distinctly advantageous, and for this purpose it might be advisable to erect roasting furnaces and other accessory plant near some railway centre that mine owners may be encouraged to send ores and concentrates there which contain precious and base metals combined with arsenic, and specially with a view of cheap treatment. Many deposits are known in the State which contain arsenic associated with very valuable metals or minerals, such as gold, silver, bismuth, tin, wolfram, and molybdenite, which at the present time are difficult or impossible to have treated in the State, the two alternatives being either to concentrate the ores and forward to southern States for treatment, or abandon the working of them altogether.

The Norton Goldfield is an area which might yield large quantities of ore containing arsenic and gold. The lodes there are numerous and large, and those which in the past have yielded gold near the surface were abandoned many years ago as soon as arsenical ores were met with at water level. The tin lodes about the Stanthorpe district, in many instances, have been found to contain arsenic, but the high charges for treatment and cost of transit to works outside the State, together with the low price given for the arsenic contents, do not warrant mine owners working the deposits under present conditions.

The Biggenden bismuth-iron lode is another example. The ore contains magnetite, bismuth and arsenic, and when the mine was being worked many years ago the process of extracting the bismuth consisted in removing the magnetite with magnetic separators, and roasting the resulting concentrates to drive off the arsenic. The arsenic was driven off in a primitive way, but the bismuth losses in roasting are not known. Were a system introduced by which the arsenic could be recovered as a by-product a concentrate could be made containing a high percentage of arsenic, which would allow of an ore being worked containing a smaller percentage of bismuth. Arsenical lodes are not uncommon in this district, and in prospecting operations a probability always exists of finding bismuth-arsenic lodes unassociated with magnetite, and perhaps as rich, if not as large, as the Biggenden lodes have in the past proved to be. The Mount Shamrock lode in the same belt of country contains gold,

bismuth and arsenic, and the concentrates yielded by this mine might develop into a very important output, particularly as they are so rich in gold and bismuth.

The arsenic generally associated with the tin, wolfram, copper and molybdenite ores of the Herberton and Chillagoe Districts and perhaps the clean mispickel lodes at Boonmoo, near Mareeba, are also to be considered, which altogether offer great inducements for mining developments if the establishment of metallurgical works were assured. With such a works as a foundation for operations, there would hardly be any doubt about Queensland becoming the leading arsenic producing State in the Commonwealth.

From a national point of view it is extremely advisable that cheap arsenic be produced, and in abundance, for the purpose of reclaiming vast areas of prickly-pear infested lands known to exist in all parts of the State. It is also necessary that action be taken to overcome the ravages of the prickly-pear, which is said to be increasing enormously every year. To produce arsenic sufficiently cheap that it may be extensively used in the reclamation of pear-infested lands, its manufacture will have to be undertaken in a large way, with perhaps new processes that will only be perfected by experiments, with a management which will show low working costs, and a plant which will furnish a product absolutely uniform in quality.

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